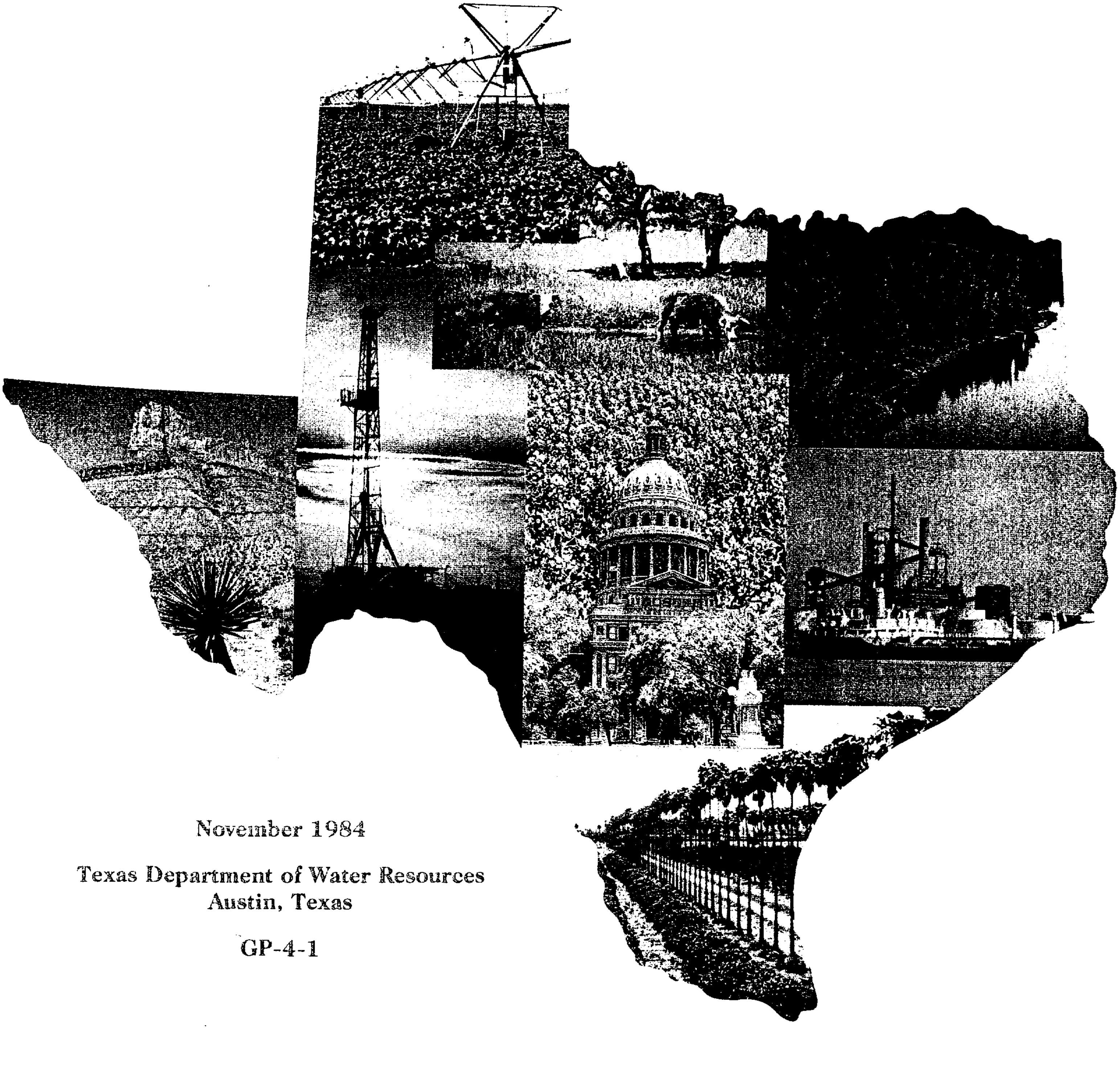
Water For Texas

Technical Appendix

Volume 2



November 1984

Texas Department of Water Resources
Austin, Texas

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Nessary

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Technical Appendix

Volume 2

Section 16.051 of the Texas Water Code directs the Executive Director of the Department of Water Resources to prepare and maintain a comprehensive State water plan for the orderly development and management of the State's water resources in order that sufficient water will be available at a reasonable cost to further the economic development of the entire State. In addition, the Department is directed to amend and modify the plan in response to experience and changed conditions.

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PREFACE

This report is a companion document to *Volume 1—WATER FOR TEXAS: A Comprehensive Plan for the Future.* This Volume contains specific technical detail about the topics and planning concepts presented in Volume 1. Current water development and use, future water needs, and potentially developable water supplies to meet projected needs are presented and described for each of the 23 major river and coastal basins in the State.

The information contained herein is based upon Texas water, demographic, economic, and technical data of the recent past. Projections of the future are based on these data and take into account estimates of future trends in economic conditions and in technology that affects water use. It is important to note that the planning information and the plans contained herein must of necessity be couched in existing water law and existing institutional arrangements affecting water resources and water use. In particular, water resources planning to meet future needs must safeguard and protect water rights that are now recognized. Planning for the future must be based upon and depart from the point of existing conditions. The materials contained herein are based upon these principles.

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PART I

INTRODUCTION AND BACKGROUND

Between 1930 and 1980, the population of Texas increased from 5.8 million to 14.2 million people, and it is projected to be between 19.6 million and 21.2 million in 2000, and between 28.2 million and 34.3 million in 2030. As the population has increased, so has the demand for water. The quantity of water used in Texas has increased from about two million acre-feet (one acre-foot is 325,851 gallons) in 1930, to about 17.9 million acre-feet in 1980. As population has increased, the economy of the State has grown, and in order to meet the future employment, economic, and social needs of the people of Texas, the economy must be continually expanded at a satisfactory rate. In order to meet acceptable levels of economic and social welfare, the people, the industries, and the environment must have sufficient supplies of suitable quality water. This can only be achieved through careful planning and timely implementation, operation, and maintenance of water quality protection, water conservation, water supply development, and flood protection facilities.

Although Texas has fifteen major river basins and eight coastal basins, which together have 3,700 streams and tributaries and more than 80,000 miles of streambed, and seven major aquifers and sixteen minor aquifers, water supplies vary widely from year to year and from place to place within the State. Average annual precipitation is 56 inches on the eastern border and less than eight inches at El Paso. Average annual recharge to aquifers is 5.3 million acre-feet. Average annual surface-water runoff is about 49 million acre-feet, but runoff ranges from about 1,100 acre-feet per square mile in the easternmost parts of the State to nearly zero in far West Texas. From 1940 through 1950—a period of high rainfall—average annual runoff was 57 million acre-feet. During the State's longest and most severe drought of record—1950 through 1956—average annual runoff was only 23 million acre-feet, leaving many parts of the State short of water.

In order to meet water needs as the Texas economy has grown, local and regional governments and federal and State agencies have developed well fields, lakes and reservoirs, and sewage collection and treatment systems. According to water use statistics obtained from annual water use surveys of the municipalities of Texas, about 50 percent of municipal water is obtained from ground-water sources. Ground water is used for municipal purposes in all areas of Texas and in practically every county. However, in many areas, the long-term use of well fields is lowering the water tables to an extent that major water supply problems are occurring, or are projected to occur, in the foreseeable future.

More than 50 percent of Texas is underlain by seven major aquifers and sixteen minor aquifers. The seven major aquifers, plus the sixteen minor aquifers, have a total average annual natural recharge of about 5.3 million acre-feet and a total recoverable reserve of about 430 million acre-feet, of which about 89 percent or 385 million acre-feet is in the High Plains (Ogallala) Aquifer in West Texas. Of the 17.9 million acre-feet of water that Texans used in 1980, about 10.85 million acre-feet was from ground-water sources. Of the 10.85 million acre-feet of ground water used, 11.9 percent or 1.29 million acre-feet was for municipal uses, 2.3 percent or 249 thousand acre-feet was for manufacturing purposes, 0.5 percent or 53 thousand acre-feet are for steam-electric power generation, 1.7 percent or 183 thousand acre-feet are for mining, 1.1 percent or 120 thousand acre-feet was for livestock watering, and 82.5 percent or 8.95 million acre-feet was for irrigation.

The dependable water supply from major reservoirs—the uniform yield that can be withdrawn annually through extended drought periods from major reservoirs—is about 11 million acre-feet annually. About 7.0 million acre-feet (64 percent) of this dependable surface-water supply is now being used. A little over 21.7 percent goes for municipal uses, 18.2 percent for manufacturing purposes, 3.9 percent for steam-electric power generation, 0.8 percent for mining, 1.8 percent is for livestock watering, and 53.5 percent for irrigation. A large portion of the remaining 4.0 million acre-feet of dependable surface-water supply is committed or planned to meet growing municipal and industrial needs of major metropolitan areas of the State over the next 30 years. This supply, however, will not meet all of the municipal and industrial needs of many Central, South, North Central, and West Texas cities where practically no dependable surface-water supplies exist. Projections also show that many cities in eastern portions of the State will need additional surface-water supplies in the immediate future. It is important to note that growth in use of surface water has been about six percent per year during the last six years, and the time required to plan and construct a typical reservoir is more than 15 years.

The maintenance and recovery of the quality of Texas' limited water supplies is absolutely essential, especially so in areas of the State that are water-short. Recognition of this fact occurred years ago and led to the passage of water quality legislation, instream water quality monitoring, and water quality standards. These standards define the quality of water necessary in each stream to provide for the beneficial uses that stream should yield. Of the more than 16,000 stream miles subject to quality standards, over 90 percent currently meet the 1983 fishable and swimmable goals of federal clean water legislation. About two percent will not be compliant due to natural conditions, leaving about eight percent of the 16,000 miles of streams needing further work to eliminate sources of pollution. It is necessary to continuously operate sewage collection and treatment systems in order to protect the quality of water in all the streams and aquifers of the State.

Increasing demands for limited quantities of water require that long-range plans be developed to meet the many water resources needs of the future. The present quantity of ground- and surface-water supplies cannot meet the projected future needs of municipalities, industry, agriculture, fisheries, and the environment. The quality of present supplies must be protected from pollution and contamination, while the quality of supplies in some parts of the State must be improved if these supplies are to be useful. Thus, it is essential that water resources plans be continually revised and amended in order to meet changing economic, social, physical, legal, institutional, and environmental conditions.

Texas water planning must be flexible with respect to local conditions of climate, hydrology, topography, and local area needs, taking into account State water law, existing rights to ground water and surface water, and local area leadership's goals and objectives with respect to growth and development. Climatic factors, including precipitation levels and seasonal distribution, temperatures, evaporation rates, solar energy levels, winds, and length of growing seasons are data relevant to each area for which water planning is to be done. Likewise, hydrology and topography affecting both the demands and supplies of water of an area are data essential to water planning.

The resource base, existing economy, and potentials for development within an area are both explicit and implicit data which must be taken into account in water resources planning. In effect, these factors are the foundations for water use in the present and establish the trends for future water supply and water quality protection needs. Particular attention must be given to the water resources needed in order to realize the potential development and use of other natural resources and capital within an area, as this development might assist in meeting local, State, national, and even international needs for employment, income, and trade. In addition, the goals and objectives of each local area must also be taken into account, since local cultural, business, and quality of life desires directly affect the need for water supplies and water quality protection.

Among the important factors affecting the use of water in Texas and long-range planning for future supplies of water is that of water rights. Ground water is recognized as private property, subject to the right of capture by landowners. Surface water is public property, the use of which is administered by the State through a system of water rights. Riparian domestic and livestock uses of surface water are exempt from the need for authorization from the Texas Department of Water Resources, and are considered as superior rights. The water rights granted or otherwise recognized by the Department have a priority status under the principal of first-in-time, first-in right, with the condition that these water rights may be subject to cancellation for nonuse.

In addition to recognizing existing water rights, water planning must also take into account the overlapping jurisdiction of federal, State, regional, and local governments, each having water resources responsibilities. Of these, the Texas Department of Water Resources is the principal State agency having water resources administration and planning responsibilities. The Texas Department of Health regulates the quality of water for public supplies and the Texas Railroad Commission regulates disposal of wastes associated with petroleum production. The Department of Water Resources working with local governments, other State agencies, federal agencies, and the private sector, and using the latest available information, ideas, and recommendations from the public, is responsible for maintaining a comprehensive statewide water plan to meet the water resources needs of Texas. In addition, the Department is responsible for the administration and enforcement of water rights permits, the administration and regulation of wastewater disposal permits, water quality protection, and the collection and analysis of various hydrologic, meteorologic, and economic data. The Department also provides some financial assistance to political subdivisions in the form of loans for water and wastewater projects and the purchase of storage capacity in local surface-water supply projects.

Federal legislation governs several water resources functions. These include flood protection, dam safety, stream quality standards and the quality of wastewater effluent that can be discharged by water users, dredge and fill in navigable waters and wetlands, navigation, hydroelectric generation, endangered species, fish and wildlife habitat protection, and cultural and environmental factors affected by water resources projects and programs. Federal agencies also assist with planning studies and in the construction and operation of major facilities such as multipurpose water projects, as well as participate in the regulation and enforcement of water quality protection, for which Congress has authorized participation and appropriated funds.

Local governments, regional water authorities, utility districts, and the private sponsor construct, operate, and maintain water supply, water quality protection, and flood protection projects and facilities. Although such functions are at the discretion of local and regional governments, all such water resources projects and services must be managed and administered in accordance with relevant and applicable State and federal laws. In these efforts, local and regional authorities are responsible for securing the necessary water rights, property, and rights-of-way, and the construction and operating permits. These local and regional authorities must also arrange financing, construct and operate facilities, pay operating costs and debt service, and repay bonds and federal contracts used in project financing. Water planning and water administration take these factors into account.

TEXAS WATER PLANNING OBJECTIVE

The objective of water resources planning is to provide a comprehensive State water plan that will serve as a flexible guide to State policy for the development, management, conservation, and protection of water resources for the State. The plan will identify and equitably consider the public and private interests and institutions of the entire State, giving appropriate attention to environmental factors, while promoting economic welfare. The plan, as a flexible guide, will identify alternative strategies for implementation in order to give direction to appropriate private and public institutions in the State to enable them to:

1. supply in a cost-effective manner sufficient quantities of suitable quality water in each area of the State, as the population and the economy of Texas grow, taking into account the practically achievable effects of improved water use efficiency and water conservation;

2. continuously protect the quality of both surface and ground water in each area of the State, and where practical and feasible, improve its quality; and,

3. provide protection of human life and public and private property from flooding and flood damage, to the extent such flood protection can be determined to be economically feasible.

Water resources planning information to be presented includes descriptions of water problems, estimates of water supplies in each area of the State, projections of future water requirements for each of 11 categories of water use in each area of the State, an identification of water conservation practices and technologies that can affect the quantity of water use, as well as identification of technologies that may have potential for extending and increasing the usable supplies of water. Present and future water quality protection needs of each area are identified, along with alternative conservation and development methods and projects. Specific analyses are given for each of the 23 river and coastal basins, including a presentation of information about the ground- and surface-water resources, economic and demographic characteristics, quantities of water use, water resource development, water rights, water conservation, water quality protection needs, and water development options within each basin.

WATER RESOURCES PROBLEMS AND POTENTIAL TYPES OF SOLUTIONS

In Texas, there is a wide range of water problems, including the contamination and the threat of pollution of existing supplies, shortages of supply to meet the needs of a dynamic and growing economy, flooding, conservation and more efficient use of water supplies, freshwater for environmental purposes, declining water tables, land subsidence resulting from ground-water use, saltwater intrusion into aquifers, increasing costs to secure water and to treat wastewater, and adequate sources of financing for sewerage, water supply, and flood protection facilities. Major problems and some potential types of solutions are identified and briefly described below.

Water Quality

There are limited supplies of water in several regions of the State, and the poor quality of some existing supplies of surface- and ground-water resources limits the quantity of usable water and increases the costs of use. Both natural contamination and man-made pollution affect the quality of existing supplies, and although different uses of water have different parameters of water quality, the degree and kind of contamination and pollution can render water unusable or perhaps too costly for use.

Natural Contamination

Several ground- and surface-water resources are presently unusable because of large concentrations of natural minerals and salts. This occurs because water is a solvent, and as such, it dissolves salts, metals, and minerals from surrounding rock and soil. Chemical materials are present to some degree in most sources of both ground and surface water. In greater concentrations, the water's usefulness is impaired.

Concentrations of salts and minerals affect several river basins in Texas, including upper reaches of the Red, Brazos, Colorado, Canadian, Pecos, and Rio Grande, and preclude the development and use of some water resources in these basins. Chloride control projects have been planned in some basins to prevent surface water with high salinity concentations from contaminating better quality water. In some areas, ground-water supplies also are adversely affected because of high concentrations of salts and minerals.

In addition to salinity, sediment also affects the quality of surface water. Soil erosion from storm and flood waters reduces the fertility of range and cropland as well as adds sediment to streams and rivers. This sediment clogs channels, reduces the storage capacity of reservoirs, and adversely affects some wildlife habitats. Controlling erosion and sedimentation through greater use of soil conservation and stabilizing measures would benefit both agriculture and water resources programs.

Pollution

Water pollution is the alteration of the quality of water to the detriment of plant or animal life or the public. Both the quantity and complexity of pollution are increasing with increasing concentrations of population and increasing levels of economic activities. While rivers, streams, and lakes are convenient for the disposal of many types of wastes, these are also the sources of water supplies in many areas and are habitats for fish and some wildlife species. Therefore, water resources must be protected from pollution. The quantity of municipal wastewater and drainage from storm sewers has increased with population and industrial growth, necessitating the installation and operation of a larger number of sewerage collection and treatment systems in order to produce effluent of suitable quality for discharge into State streams.

Some pollutants can be controlled at the point of discharge, while more dispersed sources of pollution require other measures. To meet federal and State clean water requirements, municipal and domestic wastes must have the equivalent of secondary treatment, and the use of septic tanks, except under suitable conditions, is discouraged. While industrial wastes that are discharged should receive "best practical treatment economically achievable," new technologies are needed to provide for recycling some industrial wastes and neutralizing other industrial wastes prior to any land disposal of the wastes. In addition, runoff can be managed with structural measures such as detention ponds, or nonstructural measures that include street sweeping and catch-basin maintenance. Significant progress has been made toward treating wastewater to acceptable standards for discharge into streams, but additional planning and construction of such facilities is needed and will be included in subsequent parts of this report.

Water Supply

A shortage of adequate water supplies to meet the foreseeable future municipal, industrial, and agricultural needs could occur in many regions of the State. In many areas where demand is growing, the long-range renewable supplies are quite limited. In addition, long-term dependence upon ground water, the historical water supply for much of the State, has caused ground-water resources to decline significantly. Consequently, there will be greater demand for surface-water supplies, which, in some cases, are insufficient to meet current needs during periods of drought.

In order to solve future water supply problems, it will be necessary to increase the available supplies and to increase water use efficiency through water conservation, thereby reducing demand. Techniques to increase supplies include development of new sources, recycling and reuse of some existing supplies, and increased efficiency in water use and distribution. Techniques to reduce the quantity of water required for a given population and a given economic purpose include the implementation of water conservation programs to reduce waste and to increase efficiency of use of existing supplies. Where ground-water supplies are declining, increased conservation, encouragement of recharge using flood waters, and reduced rates of pumping and use could extend the useful life of some aquifers.

In addition to increased conservation and management of water use by individuals, businesses, industries, farmers, and ranchers, meeting projected future water needs requires that supplies be increased through the development of additional reservoirs. The potential for such development is limited, and costs will be high in the future in relation to costs of similar projects in the past. As a part of planning for the future, individual reservoir projects to meet projected future needs are identified, along with an estimate of the time such projects will be needed and the costs at that time. In view of the fact that the number of suitable reservoir sites is limited, and the potential uses of such sites for other purposes may impinge upon their future availability for water supply purposes, local water supplying authorities and the State should give serious consideration to protecting such sites for water supply purposes. Since these sites are privately owned, it will be necessary to arrange for compensation of the landowners and to develop long-term management plans for the lands involved.

Flooding

Flooding is a serious problem in Texas, resulting in millions of dollars in damages annually to urban and rural areas, industry, transportation, and public utilities. Even with flood protection programs, damages from flooding will continue to increase along floodplains and in coastal areas, if these areas are selected for residential and business locations. Most people, however, do not perceive or consider the risk of flooding, and flood-prone areas continue to be developed to accommodate population and economic growth.

Since some flooding cannot be averted, the management of flood-prone areas is required to protect lives and to reduce the damages from flooding. Both structural and nonstructural flood protection measures can be used. Structural measures such as the flood-proofing of buildings and the construction of reservoirs, drainage channels, and levees provide flood protection. Nonstructural measures such as regulation of the use of flood-prone areas, regulation of land use upstream of flood-prone areas, evacuation and recovery plans, flood forecasting, and flood warnings provide means for protecting lives and property. Flood insurance provides means for compensating flood damages. Since federal funding for structural flood control projects is being reduced, State and local governments must assume more flood protection responsibilities, including flood protection planning and financing. Flood protection that is associated with water supply development is included in water planning described herein. However, more detailed local area flood protection planning is required.

Coastal Areas

Floods often occur in coastal areas as a result of inundation from heavy inland rains, hurricanes, high tides, and insufficient natural drainage. In these areas, both structural and nonstructural means can protect lives and property and reduce the damages from flooding. Structural measures applicable to flood protection in coastal areas include the construction of levees and floodways and flood-proofing existing structures. Nonstructural measures such as regulating the development of flood-prone areas, flood forecasting, advance warning, and evacuation systems should also be used to deal with flooding in coastal areas. Detailed planning for flood protection in coastal areas by local and regional governments is needed.

Inland Areas

In Texas, the character and intensity of floods differ widely on account of the varied physiography and climate within and among river basins. Because topography aggravates the severity and impact of flood waters, different flood protection measures are appropriate for different regions of the State.

Broad, flat, slow-moving floods generally occur in the upper coastal areas and eastern part of the State where rainfall is highest. Valleys are wide with gradual slopes, and timber and dense vegetation bordering rivers and streams brake the flow of runoff. This type of flood inundates these areas for prolonged periods of time and can be very damaging. Given the topography of these areas, structural measures such as flood storage in reservoirs, levees, and channelization can be used for flood protection. Nonstructural measures, including limited use of floodplains, flood insurance, and flood forecasting and warnings are also appropriate flood protection measures.

Flash floods occur in central and western regions of the State where slopes are steep, ground cover is sparse, and soils are generally thin and relatively unabsorbent. While intense, flash floods cause shorter periods of inundation. Although generally brief, these floods can be devastating. Under these conditions, both structural and nonstructural flood control measures can be used.

Water Conservation and Improving Water Use Efficiency

Through planning and management of municipal, industrial, agricultural, and other water uses, it may be possible to reduce waste and improve water use efficiency, thereby allowing existing water supplies to serve more people, meet growing industrial needs, and maintain existing levels of irrigated acreages in agriculture than would be possible otherwise. Through increased water conservation on the water demand side, the objective is to substitute management, labor, and capital for water and thereby reduce the rate of future growth in the demand for scarce water and expensive wastewater treatment facilities. In this respect, water conservation requires the adoption and use of methods and practices to prevent waste. Water conservation can be increased through the use of equipment, technologies, and management to reduce per capita water use by people, the quantities of water used per unit of product produced by industry, and the quantities of water used per acre irrigated by agriculture. However, the extent that water conservation can be used to reduce water use now and in the future, through improving water use efficiency, will be constrained by the costs of water-saving equipment and the incentive to purchase and use such equipment in the short run. In making projections of future municipal, industrial, and agricultural water requirements, conservation potentials have been taken into account. Water conservation plans are described in a later section of this report.

Municipal and Commercial Water Conservation

Currently, annual water use for municipal and domestic purposes accounts for 2.8 million acre-feet or 15.8 percent of the total water use in Texas. Long-term average daily per capita water use has increased four gallons per decade since the mid-1960's. At present rates and with expected population growth, municipal and domestic water requirements are projected to increase at least 25 percent by the year 2000 and to double by 2030. These are projected to range between 3.5 million and 5.1 million acre-feet annually in the year 2000, and between 5.1 million and 8.2 million acre-feet in 2030.

There are, however, water conserving methods available to reduce per capita water use, some at little cost. Principal methods include public information and education to encourage people to repair leaky plumbing and to more carefully manage household appliances and bathroom fixtures in order to reduce water use. Municipal plumbing codes can encourage the use of water-saving appliances, while city ordinances can encourage the use of native landscaping, permit the use of "gray water" (shower, bath, and laundry discharge) for lawn watering, and allow lot sizes and drainage grades to be selected so as to reduce the quantities of water needed for lawns and landscaping purposes.

Industrial Water Conservation

Water conservation measures are being applied in manufacturing and energy sectors to reduce energy and water costs, including costs of treating wastewater. While further reductions are possible, many require changes in the technology of production processes, which may be quite costly. If large, these added costs may reduce the competitive advantage of some industries in Texas. Additional water conservation by industry involves identifying appropriate incentives to reduce water use without unduly increasing costs.

Among the water conservation measures for industry are reduction of leaks, recycling and reuse, metering, measuring, and controlling the quantity of water used in industry. In cases where water conservation involves the purchase and use of costly equipment, governments could use tax incentives to encourage the installation of such equipment.

Agricultural Water Conservation

Future levels of irrigated agriculture in Texas are threatened by limited quantities of water supplies. Irrigation of about eight million of Texas' 30 million cropland acres uses more than 70 percent of the water used in the State, of which 75 percent is from ground-water resources having little recharge. It is important to note that irrigation is responsible for more than 40 percent or about $1.7 billion of the annual value of crops sold from Texas farms and ranches in 1980, and that data show that without improvement in irrigation efficiency, some aquifers which now supply irrigation water will be depleted to a severe degree within the next 20 years. With a high degree of water conservation, the water supplies of these aquifers could be made to support nearly 80 percent of present irrigated acreages during a foreseeable 30 to 40 year period of time, thus extending the useful life of these aquifers by 10 to 20 years.

Several water conservation techniques and practices can be used to reduce the quantities of water that need to be diverted from streams and reservoirs and the quantities that need to be pumped from wells per acre irrigated. Those conservation practices that can reduce the quantities of water diverted from surface-water sources per acre irrigated, without adversely affecting crop yields include: improvements to surface-water conveyance systems, including concrete lining of canals and the use of pipe for conveyance; scheduling and measuring quantities of water diverted; automating weirs and headgates; and pricing of water per acre-foot as opposed to charging per acre irrigated.

In the case of irrigation from ground-water sources, the use of pipe and lined canals to convey water from the wells to all parts of the fields to be irrigated can reduce the quantity of water that must be pumped per acre irrigated. In general, regardless of whether the source of irrigation water is aquifers or surface systems, several other conservation measures can reduce water use. These include: monitoring soil moisture and irrigating only when moisture conditions require it; using the knowledge of crop moisture needs in relation to growth and maturation stages and applying irrigation water only when plants need it; use of growth regulating chemicals, use of evaporation suppressants on the soil surface, and use of evapotranspiration suppressants on the plants; use of sprinklers, drip, and trickle methods to apply irrigation water; use of soil preparation and cultivation methods that retain precipitation and irrigation waters; use of crop residue as mulch; control of weeds and phreatophytes; careful monitoring and management of irrigation and cultivation systems; and, where possible, selection of less water-intensive crops and strains of crops that require less water. However, some agricultural water conservation methods mentioned here are not cost-effective at current agricultural prices and interest rates, and some methods are not well understood. Thus, technical assistance to irrigation farmers, and tax and economic incentives to adopt and use water conservation equipment, would make contributions to solving some agricultural water supply problems in the short run.

Environmental Factors

As the competition for limited water supplies increases among existing and potential users, a serious dilemma may arise involving establishment of acceptable trade-offs between the water needs of Texas' natural environmental resources and the State's social and economic needs for water. Among the environmental issues are concerns about freshwater inflows to Texas bays and estuaries, instream flow needs of the State's fish and wildlife, and protection of land resources or mitigation for loss of fish and wildlife habitat. Also at issue is how to apportion the State's surface waters among competing users as well as to determine who is responsible for paying costs associated with the provision of water for environmental uses.

Bays and Estuaries

The Texas bays, estuaries, and shallow Gulf environments of the State territorial waters (offshore boundary at nine nautical miles) are economically and ecologically important public resources. These resources provide inputs to the State economy through seafood products, tourism and recreational activities, marine commerce, and oil and gas production. In addition, these waters contain essential habitats for coastal fish and wildlife. The problems of these coastal areas are complex, involving public lands, public waters, and public wildlife.

In the 2.6 million acre estuarine area in Texas, more than 100 million pounds of seafoods is harvested annually, having an estimated annual impact on the State economy of more than $1.25 billion (1981 dollars). The fishery resources of these areas are estuarine-dependent, while the estuaries are specifically dependent on freshwater inflows for nutrients, sediments, and a viable salinity gradient for inhabiting organisms. State policy is to maintain the coastal environments and the health of their living marine resources; thus water planning work includes the collection and analyses of information about the relationships among freshwater inflows and the living organisms of the bays and estuaries. Water planning and use takes this information into account.

Instream Flows

Instream flows are necessary to retain Texas stream values for maintenance of waste assimilative capacity, general water quality, livestock water, and fish and wildlife environments. Fisheries are particularly sensitive to flow depletion that affects spawning or nursery habitats for the young. Other instream flow needs include hydroelectric, navigation, and recreation. However, the rate of streamflow needed cannot be easily generalized for such divergent uses. Moreover, significant trade-offs must occur to obtain maximum benefits from water development projects, since Texas streams must continue to provide for multiple use. Development of surface-water projects for the storage of flood flows which are released and used downstream at later dates, as well as the use, treatment, and return of wastewater effluent, some of which is from ground-water sources, provides a source of instream flows for many segments of Texas streams that would be dry during many seasons without such development.

Fish and Wildlife Habitats

Water resources development and use, and particularly the development of reservoirs, involves the inundation of large acreages of land and the associated streambeds. This, of course, is a conversion of land use from agriculture, ranching, forestry, and other purposes to reservoir sites and a change from terrestrial and stream habitat to a freshwater-lake environment. Although the lands involved are purchased at market price, thus compensating the sellers for the lands that are converted into reservoir sites, the total quantity of wildlife terrestrial and stream habitats is reduced as reservoirs are built. Lake habitat, shoreline, and waterfront types of habitat are increased. The latter group is usually considered to be a benefit in project evaluation, while the loss of terrestrial and stream habitats is considered by many to be costs for which some form of mitigation is desired. Such mitigation may be in the form of purchasing additional land to be managed specifically for wildlife habitat, the development of lakeside parks and recreation areas for public uses, the use of fish hatcheries and fisheries management programs to enhance instream fisheries downstream of lakes as well as the lake fisheries, minimum releases for downstream fish, wildlife, recreation, water quality, and other purposes, and perhaps other compensating measures. Most of these forms of mitigation are costly and if added to water supply projects, result in an increase in the cost of water to water customers.

Land Subsidence

Some aquifers in coastal areas of Texas are composed of alternating strata of sand, gravel, and clay. As water is withdrawn, pressures decrease, and the clay strata are compressed. As this phenomenon occurs, the overlying strata sink, resulting in a lowering of the elevations of land surfaces, changing of surface gradients, and the activation of faults. These changes affect drainage patterns, which aggravate flooding problems in coastal areas and increase the risk of hurricane tidal surges and flooding of coastal areas. Increased fault activity damages structures such as homes and commercial buildings, highways, airport runways, pipelines, and railroad tracks, in addition to allowing the entry of poorer quality water into ground-water resources. Subsidence is a problem in coastal areas of Texas where the water table has been lowered as freshwater has been withdrawn.

To avoid further subsidence, ground-water withdrawals must be limited to the extent that only the quantity of recharge entering the dewatered upper layers of aquifers is pumped. Further lowering of the water tables will likely result in further subsidence. Quantities of water needed above those that can be obtained from these ground-water sources must be obtained from surface sources. Planning and development of surface-water projects to meet future needs are in progress, and will be identified and described in later parts of this document.

Salt-Water Intrusion into Aquifers

Salt-water intrusion and the threat of salt-water intrusion into aquifers are present in both coastal regions and in some inland areas that now depend on ground water. Salt-water intrusion occurs from the migration of saline water from adjacent strata into areas from which large quantities of nonsaline ground water have been withdrawn without having been adequately recharged. Similar to the problem of subsidence, salt-water intrusion threatens the usefulness of aquifers. In addition to contaminating freshwater supplies, available recharge capacity is lost. Because the recovery of an aquifer from contamination is relatively slow, salt-water intrusion may become a long-term condition that precludes further use of such aquifers.

Like subsidence, measures to avert salt-water contamination include the reduction in demand for ground water through the implementation of conservation with reduced ground-water withdrawals and the development of alternative water supplies. Aquifer management techniques, including artificial recharge, may be used to assist in controlling salt movements in aquifers. In addition, in-well blending of water from saline and freshwater strata may also be used in some areas and thereby increase the total supply available. Of course, such mixtures must meet safe drinking water standards for public supply, must be carefully controlled to meet industrial water quality needs, and in the case of agriculture, must not be too concentrated to meet crop needs nor to increase soil salinity levels above those tolerated by crops.

LEGAL AND INSTITUTIONAL FACTORS AFFECTING WATER

Planning for the development and use of water and the protection of its quality must be done in accordance with provisions of State water law, interstate compacts, international treaties, federal law, established water institutions, public opinion, public preferences, public desires, and information on physical and economic conditions. Among the fundamental considerations are the distinctly different status of ownership of ground and surface water and the local, State, and federal agencies having specific authority and jurisdiction for water resources management.

Ground water is private property subject to the right of capture by owners beneath whose property ground water is found. Thus, decisions about the time and quantity of use of ground water reside with a large number of individuals whose actions are difficult to predict. Although ground water is private property, under State law, some underground water conservation districts having some regulatory powers have been formed to reduce waste, to conserve, and to manage this very important water resource. Additional such districts are needed and can be formed through referenda within areas to be affected.

In Texas, surface water flowing in public watercourses is public property, the use of which is subject to administration by the State. Texas water law has recognized claims to surface water rights granted under Spanish, Mexican, English, Republic of Texas, and United States laws, in addition to the State's Appropriation Doctrine. These claims are currently under review by the Texas Water Commission in accordance with the Water Rights Adjudication Act of 1967. Investigations of rights and claims of all 23 river and coastal basins are to be completed by 1983. Upon completion of the adjudication process, Texas surface water rights and claims will have been standardized under State law, giving priority recognition to riparian rights holders and to permits and claims having the longest history of use. The principal of first-in-time, first-in-right establishes the seniority of each recognized water use permit. However, in order to continue holding such permits, the holder must put them to beneficial use. Water rights information must also be taken into account in all water planning, so as to safeguard recognized surface-water rights. Furthermore, in planning which involves the transfer of surface water among river basins, provision must be made to meet basin of origin water needs in the foreseeable 50-year period. Only those quantities of surface water that are surplus to the basin of origin's foreseeable 50-year future needs can be considered for transfer, except on an interim basis.

Flood Control Acts of 1936 and 1938. In addition, the Watershed Protection and Flood Prevention Act of 1956 made available federal financial assistance to local political subdivisions for implementing watershed protection and flood-prevention measures. The 1968 National Flood Insurance Program established nonstructural alternatives and local floodplain management to deal with flood hazards and made available federally subsidized flood insurance.

Surface-Water Law in Texas

Sources of water generally are categorized as surface or underground. Surface water may be classified either as diffused surface water or as water within a defined watercourse. Diffused surface waters are those which occur in a natural state in places on the earth's surface other than in a watercourse, lake, or pond. In Hoefs v. Short, 114 Tex. 501, 273 S.W. 785 (1925), the Texas Supreme Court defined a watercourse as having the following legal elements:

(1) a well-defined permanent natural channel—although in places the bed and banks may be absent.

(2) a permanency of source of water—an intermittent stream can qualify despite having a channel that is dry for long periods of time if the flow of water recurs with some degree of regularity. Otherwise, it is but a ravine which is a drainage area of diffused surface water.

Rain that falls on a watershed of a stream in sufficient volume to produce concentrated runoff to make artificial irrigation valuable is a permanent source of water supply.

The point of formation of a watercourse is often difficult to establish. Waters present in a watercourse may be subclassified as (a)ordinary or normal flow, (b)underflow, and (c)storm and floodwater.

(a) The ordinary or normal flow of a watercourse has been judicially defined as a flow below the line "which the stream reaches and maintains for a sufficient length of time to become characteristic when its waters are in their ordinary, normal and usual conditions, uninfluenced by recent rainfall or surface runoff" [Motl v. Boyd, 116 Tex. 82, 286, S.W. 458 (1926)].

(b) The underflow consists of water in the sand, soil, and gravel immediately below the bed of an open stream, which supports the surface stream in its natural state or feeds it directly, together with the water in the lateral extensions of the subterranean water-bearing material on each side of the surface channel.

(c) The storm and floodwater is that portion of the flow in a watercourse derived from the diffused surface water from recent precipitation that has reached the watercourse.

Diffused surface waters are considered to be private waters and are subject to capture and use by the owners of the surface estate prior to its entry into a watercourse. No State regulation of use is exercised with respect to diffused surface water until it reaches a watercourse.

Two basic doctrines of surface water are recognized in Texas, the Prior Appropriation Doctrine and the Riparian Doctrine. The corresponding water rights perfected thereunder are commonly referred to, respectively, as appropriative rights and riparian rights. Simplistically, the riparian right arises by operation of common law concepts as an incident to the ownership of land abutting a stream or watercourse, requiring no act other than the acquisition of title to the land (but see the Water Rights Adjudication Act of 1967, discussed later). The appropriative right, on the other hand, is regulated by statute. It is not related to the land ownership and is today acquired by compliance with statutory requirements implemented by the rules and regulations of the Texas Department of Water Resources.

The Riparian Doctrine

Although not defined in Texas statutes, riparian rights are mentioned in legislative acts. Some of these statutory references appear contradictory.

In 1840, the Republic of Texas adopted the Common Law of England as the rule of decision insofar as it was not inconsistent with the Constitution and acts then in force. The judicial application and recognition of the riparian right concept in Texas began in 1856 with what appears to be the first reported Texas court decision involving any phase of water law (Haas v. Choussard, 17 Tex. 588). In this case, the court quoted with approval the classic common law riparian doctrine that, except for his natural wants, a riparian user could not diminish the quantity of water in a stream that would otherwise flow past downstream riparian owners.

A subsequent series of court decisions created considerable contradiction and confusion. Initially, the courts held that irrigation was a natural use and that downstream riparian owners could not complain if upstream riparian owners consumed the entire water supply for irrigation.

This was followed by contradictory decisions that irrigation was not a natural use of water, but was an artificial use. Still later, the courts held that if a particular stream was sufficiently large to permit irrigation without unreasonable impairment of the rights of downstream riparian owners, the use of water for irrigation would be lawful. Unlike the absolute right to use water for domestic and livestock purposes, the right to irrigate by riparian doctrine is a correlative right. In 1926, the entire subject of riparian and appropriative rights was considered by the Supreme Court of Texas in the case of Motl. v. Boyd, 116 Tex. 82, 286 S.W. 458 (1926). The court concluded that since the Mexican Colonization Law of 1823 (1 Gammel, p. 28), all of the several governments which had been sovereign in the State had recognized the right of the riparian owner to use water, not only for his domestic and household use, but for irrigation as well.

However, in 1962 the State Supreme Court, in Valmont Plantations v. The State of Texas, 163 Tex. 381, 355 S.W.2d 502, held that Spanish and Mexican grants do not have appurtenant riparian rights in the absence of specific grants of irrigation water.

The Prior Appropriation Doctrine

Historical Origin

The Prior Appropriation Doctrine evolved in the arid western states of the United States, from whence Texas water statutes were largely borrowed. Nevada, Colorado, and particularly Nebraska, contributed substantially to the text of early Texas water statutes.

Unlike the other western states which entered the union as territories, with the United States government assuming ownership of the public domain, Texas joined the union with full ownership of her land and water. Water rights to both surface and ground water in the other western states are subject to the Desert Land Act of 1853 and the Reservation Doctrine by which federal jurisdiction is asserted over uses of water which is often in conflict with state regulatory systems. However, in the early development of the West, rights to use of water from streams were not acquired by any orderly or systematic administrative procedure.

The early failure of the federal and state governments to assert control over streams as a public resource left water to be treated as though it belonged to no one, and could be appropriated in a manner similar to that of a gold claim. In the absence of public control, men took water from streams and used it; that is, they appropriated it—using the word appropriate in its ordinary sense—to take for one's own use. When water laws were enacted, this appropriation practice was legalized, and the basis of such laws became known as the Doctrine of Appropriation. This concept is contrary on the one hand to the common law doctrine of riparian right (which strictly construed demands that water must not be taken from the stream unless it can be returned undiminished in volume), and on the other hand, to a public policy of permanent governmental control under a system whereby all water is disposed of by license, which had been adopted in some European countries, the British Colonies, and a few of the arid states.

Originally the Prior Appropriation Doctrine was simply that any one needing water had the right to take it. Changed conditions in the West, resulting from population growth, and the consequent increase in demand for water, produced many limitations and modifications. Early definitions of appropriations contained in court decisions do not agree. The following is a synopsis of early equitable concepts and/or doctrines which, in combination, form the basis of the Prior Appropriation Doctrine:

Doctrine of Priority

Justice demanded that when there was not enough for all, those who first used water from a stream should have the superior right to continue that use, and the Doctrine of Priority resulted. The doctrine originated with the belief of the first settlers that their claims were superior to those of latecomers, and they insisted that the owner of the last ditch or facility built should be the first to suffer when a stream failed to supply the needs of all. The first builders of water facilities could not anticipate how many were to follow. Unless protected by some such principle, the greater their success, the sooner they would be injured by the attempts of others to benefit by their experience. The general principle that among appropriators the first-in-time is the first-in-right is now a recognized rule in the water laws of the arid regions of the United States and was so recognized by end of the last century.

Doctrine of Relation

Since many ditches were built about the same time, it became necessary to prescribe rules in determining when a right should attach. If the right should date from the time of actual use of the water, a premium would be placed upon poor construction. It might happen that during the construction of a large canal, smaller canals or those more easily built might be begun and completed and appropriate all water, leaving the large canal a total loss to its builders. To avoid this, the Doctrine of Relation evolved, that is, the right does not date from the time the water is used but relates back to the time of the beginning of the work.

Modification as to Due Diligence

To prevent abuse, the Doctrine of Relation was modified by the provision that the work of construction must be carried on continuously and with "due diligence." Under the Doctrine of Relation, a water right is initiated when the work of construction begins, and dates from that time, but is not perfected until the water has been actually diverted and beneficially used. The question of "What is due diligence?" is a question of fact to be determined in each particular case, and when such diligence is not exercised, the right dates from the time of use.

Beneficial Use Limit as to Quantity

As scarcity of water led to the adoption of the Doctrine of Priority, the two led to the necessity of defining the quantity of water to which an appropriator should be entitled. While the early appropriators were entitled to protection in their use of water, the latecomers had equal claim to protection from an enlargement of those uses. The first appropriator had the first right, but he did not have the right to take all the water he might want at any future time. His rights must, in justice to others, be defined as to quantity as well as to time. By Section 11.002 and 11.025 of the Texas Water Code, "beneficial use" has been made the measure of a right as to quantity. What constitutes "beneficial use," and the determination of the quantity of water so used, is left to the courts in most states.

Notice

With the adoption of the Doctrine of Priority, the need to provide notice of the extent of rights already acquired became apparent. Such notice was needed both for the protection of the rights already in existence, and as a warning to intending investors, of the extent to which the stream had already been absorbed.

Initially, most western states, except Colorado and Texas, required the actual physical posting of a written notice at the intended point of diversion. While this procedure was undoubtedly an adaptation of the system of "posting" a gold or mineral claim with a physical monument containing a written description of the claim, there is little similarity between a stationary gold claim and the fluid movement of water on its way to the sea.

The diversion of water without any centralized official record of the time or place of use produced much confusion and hardship when it became necessary to determine the priorities and amounts of appropriations. In early years, the absence of official records meant that facts which governed rights in the stream had to be established by testimony. Often, this determination was required many years after the irrigation appropriation had begun and continued for several generations. Eyewitnesses to the early development frequently were unavailable. The memory of those actually present was often faulty. Wide discrepancies regarding the dates of beginning the work, the size of the ditches, and the amounts of water used were the rule rather than the exception.

To achieve greater permanence, and to afford something approaching actual notice, most state statutes eventually required public registration of the claim in the office of the county clerk. Inadequate supervision coupled with poor understanding of the law by appropriators resulted in a "system" whereby all one need to do to claim his own stream or river was present a proper fee to the registry official with a document setting forth his claim.

For many streams, appropriations have been initiated which aggregate to many times the available yield. Sometimes cities claimed entire rivers without regard to earlier established concepts requiring "beneficial use." (On occasion, e.g., pueblo rights, these claims have been upheld.) Disregard, carelessness, and misunderstanding of the law and its requirements evolved into habit; habit into community accepted custom; and custom in some instances became generally, but erroneously, accepted as law. Throughout the arid western states, it is today common for holders of these early filings to flaunt them as superior vested rights—absolute and secure against the state—when there exists no relation between "beneficial use" and the appropriation claimed, and the requirement of "due diligence" has been completely disregarded.

Development of Appropriative Rights in Texas

Prior to the 1870's, Texas water legislation was limited to an 1852 Act giving each County Commissioners Court administrative control over water distribution systems within the county and to a limited number of special laws granting franchises to canal companies and to individuals authorizing the construction of specific dams and canals to utilize specified quantities of water for stated beneficial purposes.

Acts were passed in 1875 and 1876 to encourage development which authorized the donation of public lands to canal companies for canal construction. These acts were later construed to mean that the act of incorporating a canal company authorized the company to acquire a right to use water, but did not actually confer the perfected right.

The first effort to establish the Doctrine of Prior Appropriation with the State was made in the Irrigation Act of 1889. This statute was rewritten and reenacted in 1895.

The 1889 Act declared that the unappropriated waters of every stream "within the arid portions" of the State in which, by reason of the insufficient rainfall irrigation is necessary for agricultural purposes, may be diverted from its natural channel for irrigation, domestic, and other beneficial uses, provided, that water shall not be diverted so as to deprive landowners along the stream of domestic use. The 1895 Act extended the area affected to "those portions of the State of Texas in which by reason of the insufficient rainfall or by reason of the irregularity of rainfall, irrigation is beneficial for agricultural purposes." A system of registration was established which required the filing of a sworn statement describing the proposed appropriation of water with a county clerk in the county where the point of diversion was to be located. As between appropriators, the first in time was to have a prior claim to a given water supply.

In 1913, the Texas Legislature rewrote the laws relating to the use of water. The new act extended the classical system of prior appropriation to the entire State. The most important feature of the new act was the establishment of a Board of Water Engineers with original jurisdiction over all applications to appropriate water. That agency has functioned since 1913, having been renamed the Texas Water Commission in January 1962, the Texas Water Rights Commission September 1965, and the Texas Department of Water Resources effective September 1, 1977.

Certified Filings

The 1913 Irrigation Act required everyone who had constructed or partially constructed a system for the diversion and use of water, and who had actually diverted and used water prior to January 1, 1913, to file a sworn statement describing the system with the county clerk of the county where the point of diversion was located, if they had not previously done so in accordance with the acts of 1889 and 1895 and to file such with the Board of Water Engineers. The act also required anyone who had actually taken or diverted water for beneficial use prior to January 1, 1913, to file a certified copy of the previous statement describing the system and the amount and purpose for which water was diverted and used with the Board of Water Engineers. An initial time limit of one year for compliance with the provision was later extended to 1916. In 1964, in State Board of Water Engineers v. Slaughter, 382 S.W.2d 111 (TEX.CIV.APP.-San Antonio 1964, writ ref'd-.n.r.e.), the requirement of filing a sworn statement with the Board of Water Engineers was held to be directory only. The act provided that those who filed with the Board "shall, as against the State, have the right to take and divert such water to the amount or volume thus being actually used and applied."

Together, the two statements and map filed with the Board came to be known as "certified filings" and are now so defined by statutes. Many of these filings declared an intent to irrigate several hundred thousand acres of land. Many of these large filings were never developed in accordance with the sworn statement describing the irrigation system, nor have the vast acreages been irrigated. Some of these undeveloped certified filings have been canceled in whole or in part by subsequent action of the Texas Water Commission. The extent to which other undeveloped certified filings will be recognized as vested rights to water use remains one of the several unresolved questions affecting optimum development of the water resources within the State. It is a matter of conjecture as to how many of these early rights could be maintained in litigation today since many declared appropriations (1) were never attached by virtue of lack of due diligence, or (2) were never limited as to quantity measured by "beneficial use," or (3) have been abandoned.

Appropriative Permits

The Irrigation Act of 1913 was revised and reenacted in 1917. A principal feature of the Act of 1917 authorized the Texas Board of Water Engineers to adjudicate water rights. This provision of the act was held unconstitutional in 1921. The Act of 1917, without the adjudicative provision, was reenacted in the 1925 revision of the Texas Civil Statutes and, with numerous amendments, remains the statutory basis for appropriative rights concepts in the State today.

Present-day statutes retain the cornerstone of the Doctrine of Prior Appropriation in that "as between appropriators, the first in time is the first in right." To this cornerstone, the statutes add the following concept of actual beneficial use as a limit to the measure and extent of a perfected water right: "A right to use State water under a permit or a certified filing is limited not only to the amount specifically appropriated but also to the amount which is being or can be beneficially used for the purposes specified in the appropriation, and all water not so used is considered not appropriated" §11.025, Texas Water Code. Beneficial use is defined as "the amount of water which is economically necessary for a purpose authorized by this chapter, when reasonable intelligence and reasonable diligence are used in applying the water to that purpose" (Section 11.002(3), Texas Water Code).

In 1931, the Wagstaff Act was enacted which provided that "any appropriation made after May 17, 1931, for any purpose other than domestic and municipal use, is subject to the right of any city or town to make appropriations of water for domestic or municipal use without paying for the water." The Rio Grande was specifically excluded (Section 11.028, Texas Water Code).

In Texas today, anyone who desires to appropriate water must make an application in writing to the Texas Department of Water Resources. The Texas Water Commission of the Department, as a regulatory agency with broad discretionary powers, is charged with the administration of rights to the surface-water resources of the State. The Commission consists of three members appointed by the Governor for six-year staggered terms with the consent of the Senate. The Chairman is designated by the Governor.

The Rules of the Texas Department of Water Resources prescribe the procedures for applying for a water permit. The Department and the Commission will consider an application for approval if the application is in proper form and complies with statutory provisions. It may be granted only if unappropriated water is available, if the application contemplates a beneficial use of water, does not impair existing water rights or vested riparian rights, and is not detrimental to the public welfare.

After approval of an application, the Commission issues a permit giving the applicant the right to take and use water only to the extent stated. Permits may be regular, seasonal or temporary, or emergency in nature. A regular permit may be permanent in nature or issued for a term, and does not limit the appropriator to the taking of water during a particular season or between certain dates. A seasonal permit is also normally issued in perpetuality, but the taking of water is limited to certain months or days during the year. A temporary permit is granted for a period of time not exceeding three years and does not vest in the holder any permanent right to the use of water.

The Texas Water Commission may also grant permits for the impoundment and storage of water with the use of the impounded water to be determined at a later date by the Commission.

Once the right to the use of water has been perfected by the (1) issuance of a permit from the Texas Water Commission and (2) the subsequent beneficial use of the water by the permittee, the water authorized to be appropriated under the terms of the particular permit is not subject to further appropriation until the permit is cancelled. Formal cancellation of unused permits, certified filings, or certificates of adjudication is possible by administrative action initiated by the Executive Director and subsequent Commission hearings.

Section 11.142 (formerly Article 7500a) allows a landowner to construct a dam and reservoir on his own property, that is, on a nonnavigable stream, and to impound not to exceed 200 acre-feet of water for domestic and livestock purposes only, without securing a permit. A simplified, short form application for permit to appropriate water for other than domestic and livestock purposes is available for the owner of such an exempt reservoir which was originally built for domestic and livestock purposes.

Water Rights Adjudication

In 1956, the Attorney General of Texas filed suit in the 93rd District Court of Hidalgo County seeking a judicial adjudication of the water rights to the American share of the waters of the Rio Grande on that segment of the river lying immediately below the International Falcon Dam and extending to the mouth of the Rio Grande.

After a lengthy trial, on August 1, 1966, District Judge J.H. Starley rendered an order, but attempted to retain continuing jurisdiction. In 1969, a landmark decision, the State of Texas v. Hidalgo County Water Control District No. 18, 443 S.W.2d 728, the Corpus Christi Court of Civil Appeals entered a judgment modifying and affirming the trial court judgment. Writ of error was refused by the Texas Supreme Court.

In an earlier decision, of Valmont Plantations v. State, in 1962, the Supreme Court of Texas affirmed the decision of the Court of Civil Appeals and adopted it as its opinion. This was an appeal out of the same lawsuit. It held that the original Spanish and Mexican grants did not carry with them rights of irrigation unless the rights were specific in the grants.

While the Hidalgo County Water Control and Improvement District No. 18 decision, commonly known as the Lower Valley Case, is a momentous ruling, the segment adjudicated is unique in two respects: (1) the Rio Grande is an international stream upon which Falcon and Amistad Reservoirs were constructed under a treaty without an allocation of the American share of the storage therein, and (2) the lower valley has a long history of development for irrigation.

In 1967, the Texas Legislature enacted the Water Rights Adjudication Act which is codified as Section

11.301 et seq. of the Texas Water Code. The declared purpose of the act was to require a recordation with the Texas Water Rights Commission of claims of water rights which were presently unrecorded, to limit the exercise of those claims to actual use, and to provide for the adjudication and administration of water rights. Pursuant to the act, all persons wishing to be recognized water rights at the end of the administrative adjudication who were claiming water other than under permits or certified filings were required to file a claim with the Commission by September 1, 1969. Such a claim is to be recognized only if valid under existing law and only to the extent of the maximum actual application of water to beneficial use without waste during any calendar year from 1963 to 1967, inclusive. Riparians were allowed to file an additional claim on or before July 1, 1971, to establish a right based on use from 1968 to 1970, inclusive.

Pursuant to the authority and responsibility of this act, The Texas Water Rights Commission (now the Texas Water Commission of the Texas Department of Water Resources) initiated a series of administrative adjudications of water rights other than domestic and livestock uses on a river segment by river segment basis as shown by the accompanying table and map. After an initial investigation by a Department engineer, and required notices, claimants are afforded an administrative hearing conducted by the Commission to show the nature and extent of their claim. After the Commission renders a preliminary determination, which includes an evaluation of each claim presented in the segment, affected claimants in the adjudication are afforded an opportunity to file contests. At the contest hearings, claimants and protestants are again given an opportunity to present additional evidence and oral argument. The Commission then enters a final determination. After ruling on motions for rehearing from the final determination, the Commission is required to file a certified copy of the final determination, together with all evidence presented to or considered by it, in a district court of any county in which the stream segment is located. After a final hearing, the Court enters a decree affirming or modifying the order of the Commission. Section 11.326 of the Texas Water Code provides that the Executive Director may appoint a watermaster for the purpose of administrating adjudicated water rights in those areas of the State where adjudication has become finalized.

On February 29, 1984, the adjudication process was about 91 percent complete, with plans for completion of all investigations by September 1, 1984, with the exception of the Rio Grande segment above Fort Quitman. Work in this area is not underway because of litigation.

The question of constitutionality of the Water Rights Adjudication Act has been resolved. On November 24, 1982, in re: The Adjudication of Water Rights in the Llano River Watershed of the Colorado River Basin, the Supreme Court of Texas rendered the decision that the act is constitutional.

Ground-Water Law in Texas

As a prelude to any discussion of the ground-water law of Texas, it is desirable to understand the term "ground water" as defined by statute and case law. A more accurate term would probably be percolating water.

Percolating waters are defined as those waters below the surface of the ground not flowing through the earth in known and defined channels, but are waters percolating, oozing, or filtrating through the earth. Percolating waters are distinguished from: (1) "subterranean streams flowing in well-defined beds and having ascertainable channels" and (2) "the ordinary underflow of every river and natural stream of the state."

The state of the law with respect to ownership of subterranean streams flowing in well-defined channels is not settled in Texas. However, "stream underflow" (the water that flows beneath and alongside of a surface stream channel) is the property of the State (Section 11.021, Texas Water Code). Both stream underflow and subterranean streams have been expressly excluded from the definition of underground water in Section 52.001 of the Texas Water Code, which article recognizes the ownership and rights of Texas landowners to underground water.

There exists a legal presumption in Texas that all sources of ground water are percolating waters as opposed to subterranean streams. The courts in the past have been reluctant to accept testimony of engineers and hydrologists as conclusively rebutting this presumption. Consequently, the surface landowner is presumed to own underground water until it is conclusively rebutted by a showing that the source of such supply is a subterranean stream or stream underflow, a burden of proof that may be very difficult to carry.

Texas courts have followed unequivocally the "English" or "common law" rule that the landowner has a right to take for use or sale all the water he can capture from beneath his land. The judiciary early chose not to adopt the "American rule" with respect to ground water, which is based on "reasonable use" and correlative rights. Consequently, neither an injured neighbor nor the State can effectively exercise control over water-use practices involving ground water. This is in contrast with the extensive and direct involvement of the State in conserving and controlling surface-water supplies. The situation is paradoxical when one realizes the actual interrelationship of ground and surface water, and even more so when one realizes the

PERTINENT DATES IN ADJUDICATION PROGRAM

BASIN STREAM SEGMENTS OR WATERSHEDS	INVESTIGATION BEGAN	PUBLISHED REPORT	NOTICE FOR 11.307 CLAIMS	11.307 CLAIMS DUE	EVIDENTIARY HEARINGS SCHEDULED	EVIDENTIARY HEARINGS COMPLETE	PUBLISHED PRELIMINARY DETERMINATION	NOTICE FOR CONTESTS	CONTESTS DUE	CONTEST HEARINGS SCHEDULED	CONTEST HEARINGS COMPLETE	PUBLISHED FINAL DETERMINATION	NOTICE FOR MOTIONS ON REHEARINGS	DATE FOR ACTION ON MOTIONS	PUBLISHED MODIFIED FINAL DETERMINATION	FINAL DETERMINATION TO ATTORNEY GENERAL	FINAL DETERMINATION FILED DISTRICT COURT	DISTRICT COURT NO. AND CITY	FINAL JUDGEMENT ISSUED	CERTIFICATES OF ADJUDICATION ISSUED	NUMBER OF CERTIFICATES ISSUED
A. RIO GRANDE BASIN																					
1. Lower Rio Grande	Adjudicated By The 93rd District Court With Modifications By Appellate Court																				
a. Tributaries	1-26-84	3-18-84	6-18-84	10-5-84	10-19-84																879
2. Middle Rio Grande	8-8-66	11-1-68	10-22-69	2-20-70	7-15-70	5-25-71	8-30-72	4-9-73	7-16-73	8-28-73	8-29-73	10-15-74	10-15-74	11-15-74	2-27-75	4-22-75	5-2-75	200-AUSTIN	11-9-82/	8-15-83/	179/
3. Upper Rio Grande	10-15-68	4-1-71	8-30-71	12-20-71	3-28-72	3-1-74	5-15-74	8-1-74	9-16-74	12-19-74	8-12-75	1-19-76	2-18-76	2-19-76	—	3-9-76	3-12-76	201-AUSTIN	8-13-76	8-18-77	107
4. Pecos-Devils Rivers	7-8-69	6-1-71																			
a. Barrilla Draw	10-1-69	6-1-71	11-2-72	2-20-73	4-24-73	6-14-74	12-17-74	12-17-74	4-16-75	7-15-75	7-15-75	11-10-75	11-10-75	12-10-75	—	1-14-76	3-10-76	112-FORT STOCKTON	6-6-78	9-28-78	13
5. Rio Grande above Ft. Quitman																					
B. COLORADO RIVER BASIN																					
1. Concho River	9-1-71	9-8-72	9-11-72	1-8-73	3-6-73	8-30-74	4-14-75	4-14-75	7-28-75	9-23-75	10-29-75	3-1-76	3-1-76	4-25-76	8-16-76	10-13-76	11-1-76	51-SAN ANGELO	6-14-79	3-12-80	220
2. Upper Colorado River	11-15-71	5-1-73	4-25-73	7-27-73	9-4-73	8-9-74	10-30-74	1-15-75	4-17-75	7-15-75	8-12-75	2-2-76	2-2-76	3-3-76	—	3-17-76	4-6-76	51-SAN ANGELO	9-10-76	8-19-77	149
3. Pecan Bayou	12-19-72	2-15-74	2-19-74	5-21-74	6-24-74	10-22-74	4-14-75	4-14-75	7-28-75	9-22-75	10-29-75	3-1-76	3-1-76	4-25-76	—	5-27-76	6-10-76	27-GOLDTHWAITE	9-14-79/11-23-82	4-13-81/6-1-83	105/2
4. Middle Colorado River	9-15-72	5-15-75	5-19-75	9-2-75	10-7-75	11-10-76	8-20-79	9-24-79	1-7-80	3-26-80	4-8-80	3-16-81	4-29-81	6-29-81	9-14-81	11-20-81	12-10-81	33-BURNET	3-18-82/10-29-82	8-31-83	182
5. San Saba River	3-10-73	4-1-75	4-8-75	7-21-75	8-25-75	4-30-76	8-31-77	8-31-77	1-12-78	3-13-78	3-29-78	3-28-79	3-28-79	5-4-79	—	6-21-79	7-9-79	33-SAN SABA	9-19-79/1-7-83	4-20-81/2-7-83	165/1
6. Llano River	12-1-73	8-20-75	12-15-75	4-1-76	5-17-76	4-14-77	8-31-77	8-31-77	1-12-78	3-16-78	3-16-78	4-4-78	4-4-78	7-7-78	—	7-20-78	9-25-78	33-LLANO	9-24-79/11-24-82	8-15-80/3-8-83	177/1
7. Lower Colorado River	9-19-73	2-20-76	4-26-76	8-16-76	10-18-76	4-20-78	8-31-82	10-8-82	1-10-83	1-11-84	5-17-84										
8. Pedernales River	11-26-73	9-1-75	12-15-75	4-1-76	5-3-76	10-1-76	1-23-78	7-19-78	11-3-78	12-11-78	12-11-78	3-1-79	3-1-79	4-6-79	—	4-13-79	4-26-79	200-AUSTIN	7-2-79	8-15-80	78
C. SAN ANTONIO RIVER BASIN																					
1. Cibolo Creek	8-19-70	10-4-71	11-15-71	3-15-72	7-27-72	9-27-72	5-29-73	5-29-73	9-10-73	11-28-73	11-28-73	12-31-73	3-19-74	4-16-74	8-5-74	10-4-74	10-7-74	73-SAN ANTONIO	7-28-77	9-28-78	30
2. Medina River	2-19-71	6-1-73	8-29-74	12-3-74	1-6-75	3-13-75	9-9-76	9-2-76	1-31-77	5-2-77	7-14-77	12-5-77	12-5-77	2-15-78	5-23-78	9-7-78	11-20-78	37-SAN ANTONIO	11-12-80/	8-28-81/	54/
3. San Antonio River	8-21-72	11-15-73	9-16-74	1-20-75	3-18-75	8-6-75	10-18-76	10-19-76	3-4-77	4-18-77	5-16-77	8-15-77	10-18-77	11-3-77	—	2-6-78	3-27-78	57-SAN ANTONIO	10-3-80	7-29-82	55
D. GUADALUPE RIVER BASIN																					
1. Upper Guadalupe River	10-18-71	12-15-72	1-15-73	5-1-73	6-25-73	1-23-74	7-30-75	7-30-75	12-16-75	4-5-76	2-17-77	3-28-77	3-28-77	6-24-77	—	7-18-77	9-9-77	57-SAN ANTONIO	11-12-79/11-24-82	7-17-81/3-8-83	134/14
2. Lower Guadalupe River * * *	1-22-73	12-5-75	11-21-77	3-3-78	5-1-78	1-10-79	4-15-80	5-12-80	8-11-80	10-28-80	2-20-81	10-13-82	12-3-82	2-8-83	—	4-28-83	2-16-84	267-VICTORIA	6-25-84/		
3. Blanco-San Marcos Rivers	10-28-72	12-20-77	4-10-78	7-28-78	9-11-78	4-2-79	8-10-79	8-14-79	12-17-79	2-20-80	3-4-80	6-3-80	6-30-80	8-29-80	—	9-24-80	10-7-80	200-AUSTIN			
E. NUECES RIVER BASIN																					
1. Lower Nueces River	7-23-73	7-22-74	11-21-77	3-3-78	5-22-78	7-15-80	3-19-81	4-17-81	7-17-81	9-3-81	9-3-81	11-4-81	11-25-81	1-26-82	1-26-82	2-9-82	6-30-82	214-CORPUS CHRISTI	9-23-82	6-30-83	7
2. Upper Nueces River	12-2-74	5-22-78	6-26-78	10-6-78	11-13-78	7-20-79	2-20-80	2-26-80	7-1-80	9-17-80	9-26-80	6-18-81	7-24-81	9-9-81	—	9-18-81	10-28-81	38-UVALDE	9-18-82	1-24-84	128
3. Frio-Atascosa Rivers	11-11-74	4-26-76	3-27-78	7-14-78	8-28-78	3-22-79	3-13-80	4-11-80	7-17-80	9-16-80	10-31-80	5-20-81	6-26-81	8-19-81	—	9-2-81	1-29-82	73-SAN ANTONIO	4-12-82/	5-11-84/	78/
F. BRAZOS RIVER BASIN																					
1. Brazos I	5-17-76	8-31-78	12-19-79	4-11-80	4-21-80	6-2-80	2-27-81	4-1-81	7-6-81	9-15-81	9-15-81	2-10-82	3-18-82	5-5-82	—	6-22-82	9-13-82	39-HASKELL	11-18-82		
a. Salt & Double Mt. Forks	5-17-76	8-31-78	2-13-79	5-18-79	5-21-79	8-31-79	1-6-81	2-9-81	5-13-81	7-13-81	7-13-81	2-10-82	3-18-82	5-5-82	—	6-22-82	9-13-82	39-HASKELL	11-18-82		
2. Brazos II	9-12-77	1-9-79	2-6-80	5-23-80	6-2-80	4-1-81	4-14-82	5-25-82	8-31-82	11-17-82	1-7-83	4-6-83	5-6-83	6-28-83	9-20-83	1-25-84					
3. Brazos III	8-7-78	2-1-83	2-10-83	5-16-83	5-23-83	7-10-84															
4. Brazos IV * *	6-19-78	6-15-83	7-27-83	10-28-83	11-7-83	8-8-84															
5. Clear Fork	4-5-76	6-15-78	5-4-79	8-31-79	9-10-79	4-2-80	6-10-82	7-15-82	10-18-82	3-9-83	6-3-83	6-11-84	6-1-84	8-1-84							
6. Little River	1-20-76	7-1-77	9-17-79	1-7-80	1-21-80	8-26-80	11-24-81	2-8-82	5-11-82	7-21-82	9-1-82	12-14-82	1-20-83	3-29-83	—	4-28-83	9-20-83	26-GEORGETOWN	4-30-84/		
7. Lower Leon River	8-1-75	2-22-77	9-14-79	1-4-80	1-14-80	7-31-80	5-13-81	6-19-81	9-25-81	12-1-81	1-5-82	6-2-82	7-26-82	9-8-82	—	10-28-82	10-29-82	35-BURNET	1-7-83	4-30-84	102
8. Middle Leon River	2-2-76	11-1-77	6-22-79	10-1-79	10-29-79	5-2-80	2-17-81	3-17-81	6-18-81	8-11-81	8-11-81	11-5-81	12-7-81	1-26-82	—	2-5-82	4-1-82	52-GATESVILLE	4-20-83/	10-31-83/	95/
9. Upper Leon River	12-12-74	6-1-77	3-28-79	7-16-79	7-23-79	4-1-80	12-16-81	2-5-82	5-7-82	6-29-82	6-29-82	9-15-82	10-20-82	12-8-82	—	12-8-82	6-2-83	35-GOLDTHWAITE	9-8-83		
10. Bosque River	12-13-76	2-28-78	8-7-78	11-20-78	1-15-79	8-10-79	6-10-80	7-11-80	10-10-80	1-7-81	3-26-81	6-10-81	7-16-81	9-16-81	—	10-2-81	10-19-81	19-WACO	1-5-82/2-8-84	3-8-83	118
11. Brazos River Authority	12-12-74	6-15-83	8-10-84	11-12-84	11-12-84																
G. TRINITY RIVER BASIN																					
1. Upper West Fork	5-12-75	2-15-79	2-23-79	6-8-79	6-11-79	8-23-79	7-30-80	8-29-80	12-5-80	4-27-81	4-28-81	12-8-81	1-15-82	3-24-82	3-29-82	5-27-82	9-30-82	160-DALLAS	1-14-83/		
2. Middle West Fork	5-12-75	4-5-79	6-6-79	9-20-79	9-24-79	3-6-80	10-9-80	11-7-80	2-6-81	Upper West Fork, Middle West Fork And Lower West Fork Combined Into One Segment And Titled The West Fork Trinity River											
3. Lower West Fork	5-12-75	5-25-79	6-6-79	9-20-79	9-24-79	3-6-80	10-9-80	11-7-80	2-6-81												
4. Upper Trinity River	3-3-75	4-11-77	2-28-77	6-6-77	6-20-77	5-31-78	4-11-79	4-11-79	8-24-79	10-2-79	10-25-79	6-23-80	7-21-80	9-19-80	11-17-80	3-17-81	6-18-81	160-DALLAS	10-29-81/1-21-83	7-22-83	111
5. Middle Trinity River	8-28-78	4-20-82	4-29-82	7-9-82	7-26-82	3-21-84															
6. Lower Trinity River *	4-18-77	7-31-79	10-7-80	1-8-81	1-19-81	3-30-82															
H. RED RIVER BASIN																					
1. Upper Red River	5-12-80	5-11-81	5-20-81	8-21-81	8-31-81	11-10-82	3-16-83	4-18-83	7-18-83	10-4-83	11-21-83	8-1-84	9-10-84	10-18-84							
2. Middle Red River	8-25-80	2-25-82	4-5-82	8-13-82	8-30-82	4-6-83	3-15-84	4-17-84	7-18-84	9-18-84											
3. Lower Red River	11-30-81	12-27-82	1-21-83	4-11-83	4-25-83																
I. NECHES RIVER BASIN																					
1. Upper Angelina River	1-9-78	5-15-79	2-19-80	6-13-80	6-23-80	12-18-80	9-3-82	10-15-82	1-20-83	3-24-83	3-24-83	4-18-84	8-21-84	7-10-84							
2. Upper Neches River	7-18-77	3-15-79	11-26-79	3-10-80	3-24-80	9-19-80	4-16-81	5-15-81	8-14-81	10-13-81	10-15-81	2-23-82	3-30-82	5-18-82	—	5-12-82	5-28-82	241-TYLER	10-11-82/5-10-83		
3. Lower Neches - Angelina Rivers *	2-20-78	4-15-80	6-16-80	9-26-80	10-13-80	10-1-82															
J. SABINE RIVER BASIN																					
1. Upper Sabine River	8-21-78	2-1-82	2-10-82	5-25-82	6-14-82	2-25-83															
2. Lower Sabine River	6-8-81	6-4-82	6-15-82	9-10-82	9-20-82	6-28-83															
K. CANADIAN RIVER BASIN	6-4-79	1-31-80	5-30-80	9-5-80	9-8-80	2-3-81	7-14-82	8-20-82	11-30-82	—	—	1-10-83	2-1-83	4-12-83	—	4-28-83	2-29-84	100-AMARILLO	7-5-84		
L. SULPHUR RIVER BASIN	10-1-79	8-14-81	9-4-81	12-10-81	12-14-81	4-13-82	2-17-83	4-15-83	7-18-83	11-2-83	11-3-83										
M. CYPRESS CREEK BASIN	4-9-79	2-15-82	2-23-82	5-25-82	6-14-82	1-5-83															
N. SAN JACINTO RIVER BASIN	10-11-77	2-25-80	2-21-80	5-30-80	6-9-80	1-22-81	6-8-82	7-9-82	10-8-82	12-14-82	2-10-83	10-25-83	11-22-83	1-4-84	—	2-16-84					
O. LAVACA RIVER BASIN * * *	8-7-78	1-9-79	1-26-79	5-4-79	5-7-79	7-2-79	12-18-79	12-21-79	4-21-80	—	—	6-4-80	6-30-80	8-14-80	—	8-26-80	9-25-80	155-LA GRANGE	1-14-81	7-3-81	28
P. COASTAL BASINS																					
1. Trinity - San Jacinto	4-18-77	4-20-79	6-16-80	9-26-80	10-6-80	12-16-80	2-16-82	3-11-82	6-11-82	7-21-82	7-21-82	10-6-82	11-8-82	12-21-82	—	12-21-82	12-20-83	253-LIBERTY	4-12-84		
2. Brazos - Colorado	3-24-80	10-1-80	10-24-80	2-13-81	2-23-81	5-14-81	4-29-82	6-8-82	9-10-82	11-18-82	11-19-82	4-12-83	5-17-83	7-5-83	—	8-24-83	4-4-84	25-COLUMBUS	6-19-84		
3. Colorado - Lavaca	8-6-79	12-17-79	2-11-80	6-13-80	6-23-80	9-4-80	9-30-82	11-19-82	2-21-83	6-1-83	7-19-83										
4. San Antonio - Nueces	4-12-81	10-20-82	10-28-82	2-14-83	2-21-83	11-1-83															
5. Nueces - Rio Grande	7-14-80	10-20-82	10-28-82	2-14-83	2-21-83	1-18-84															
6. Neches - Trinity	*	Included With The Lower Trinity River And Lower Neches - Angelina Rivers Segment																			
7. San Jacinto - Brazos	* *	Included With The Brazos IV Segment																			
8. Lavaca - Guadalupe	* * *	Included With The Lower Guadalupe River Segment And Lavaca River Basin																			

ACCOMPLISHED DURING FISCAL YEAR 1984

Reflects Progress Thru August 31, 1984


TEXAS DEPARTMENT OF WATER RESOURCES
ADJUDICATION PROGRAM
STATE OF TEXAS
Austin, Texas
Reflects Progress Thru August 31, 1984
CANADIAN
UPPER RED
RED
SALT & DOUBLE MT FORK
MIDDLE RED
LOWER RED
SULPHUR
CYPRESS
BRAZOS I
BRAZOS
CLEAR FORK
BRAZOS II
BRAZOS III
BRAZOS IV
UPPER TRINITY
WEST FORK
TRINITY
MIDDLE TRINITY
LOWER TRINITY
UPPER SABINE
SABINE
UPPER NECHES
NECHES
UPPER ANGELINA
LOWER NECHES-ANGELINA
LOWER
UPPER COLORADO
COLORADO
CONCHO
PECAN BAYOU
UPPER LEON
LOWER LEON
MIDDLE LEON
BOSQUE
MIDDLE COLORADO
SAN SABA
LITTLE
LLANO
PEDERNALES
LOWER COLORADO
SAN JACINTO
LAVACA
UPPER GUADALUPE
BLANCO
SAN MARCOS
LOWER GUADALUPE
CIBOLO
SAN ANTONIO
MEDINA
FRIO
ATASCOSA
NUECES
UPPER NUECES
LOWER NUECES
MIDDLE RIO GRANDE
RIO GRANDE ABOVE FORT QUITMAN
CLOSED BASIN
PECOS AND DEVILS
RIO GRANDE
BARRILLA
UPPER RIO GRANDE
TRIB
LOWER RIO GRANDE
GULF OF MEXICO
NECHES-TRINITY
TRINITY-SAN JACINTO
SAN JACINTO-BRAZOS
BRAZOS-COLORADO
COLORADO-LAVACA
LAVACA-GUADALUPE
SAN ANTONIO-NUECES
NUECES-RIO GRANDE

necessary interrelationship of ground- and surface-water development for future State needs and the necessity of adequate ground-water supplies to meet future municipal and domestic requirements in certain areas.

Owners of land overlying defined ground-water reservoirs may adopt voluntary well regulation through mutual association in underground water conservation districts: Section 52.001, Texas Water Code provides the framework for these districts, and to date, 12 have been created, but only nine are currently active.

Impairment of a landowner's right in the percolating waters under his land, when this impairment is the result of a trespass on the land is, of course, actionable. To date there are only three legal actions available to a landowner in Texas for outside interference with his percolating water rights. The first is the common law right recognized in jurisdictions which apply the English rule. This right arises when there is malice or wanton conduct which results in a taking for the for sole purpose of injuring a neighbor. The second action recognized in Texas arises when artesian flow results in no beneficial use, and as such, is defined as "waste." Section 11.205 of the Texas Water Code defines "waste" in relation to artesian wells, and provides, among other exceptions, that waste will not exist if the water is "used for the purposes and in the manner in which it may be lawfully used on the premises of the owner of such well." The third action arises as a result of contamination of the quality of water in a landowner's well. Cases within the third category have arisen mostly in areas where it can be conclusively shown that oil and gas operations have allowed brines, oil, and other substances to escape into the percolating freshwater-bearing strata. See Continental Oil Company v. Berry, 42 S.W.2d 953, (TEX.CIV.APP.-Fort Worth 1932, writ ref'd).

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PART II

WATER RESOURCES AND WATER DEMANDS

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PART II

WATER RESOURCES AND WATER DEMANDS

In this section, the components and quantities of the State's water resources are identified and described. Methods, data, and assumptions whereby projections were made of future water quality protection and water supply needs of each area of the State are also presented and explained, along with the resulting projections of the State totals. Projections for individual zones and river basins are presented in Part III. The quantity of water that was estimated to have been used in 1980 is shown. Estimates are based upon reported use of water for municipal, commercial, and manufacturing purposes, and surveys of agricultural water use. Projections of quantities of water that will be needed in the future are shown here and in Part III for each decade from 1990 through 2030.

PROJECTING FUTURE WATER SUPPLIES

The source of water in each area of the State is precipitation, although everyday current supplies are obtained from storage in aquifers, storage in reservoirs, and flowing streams. In Texas, the particular climate and physiography combine to affect the distribution of precipitation across the State. Also, certain characteristics of the climate—temperature, drought, hurricanes, and other weather phenomena—affect the quantity of precipitation that occurs in different regions of the State. Weather, ground water, and surface water resources are described in the following discussion.

Weather and Climate

The climate of Texas is characterized by variations in the weather. There are wide variations in precipitation and temperature across the State. This is determined primarily by the confluence of warm, moist Gulf air and relatively cool, dry air from the continental United States. While the western half of the State has a semi-arid, continental-type climate, characterized by rapid and drastic fluctuations in temperature, the remainder of the State is influenced by a humid, subtropical climate, having moderate temperatures. Thus, the different parts of the State receive quite different quantities of precipitation annually.

Precipitation

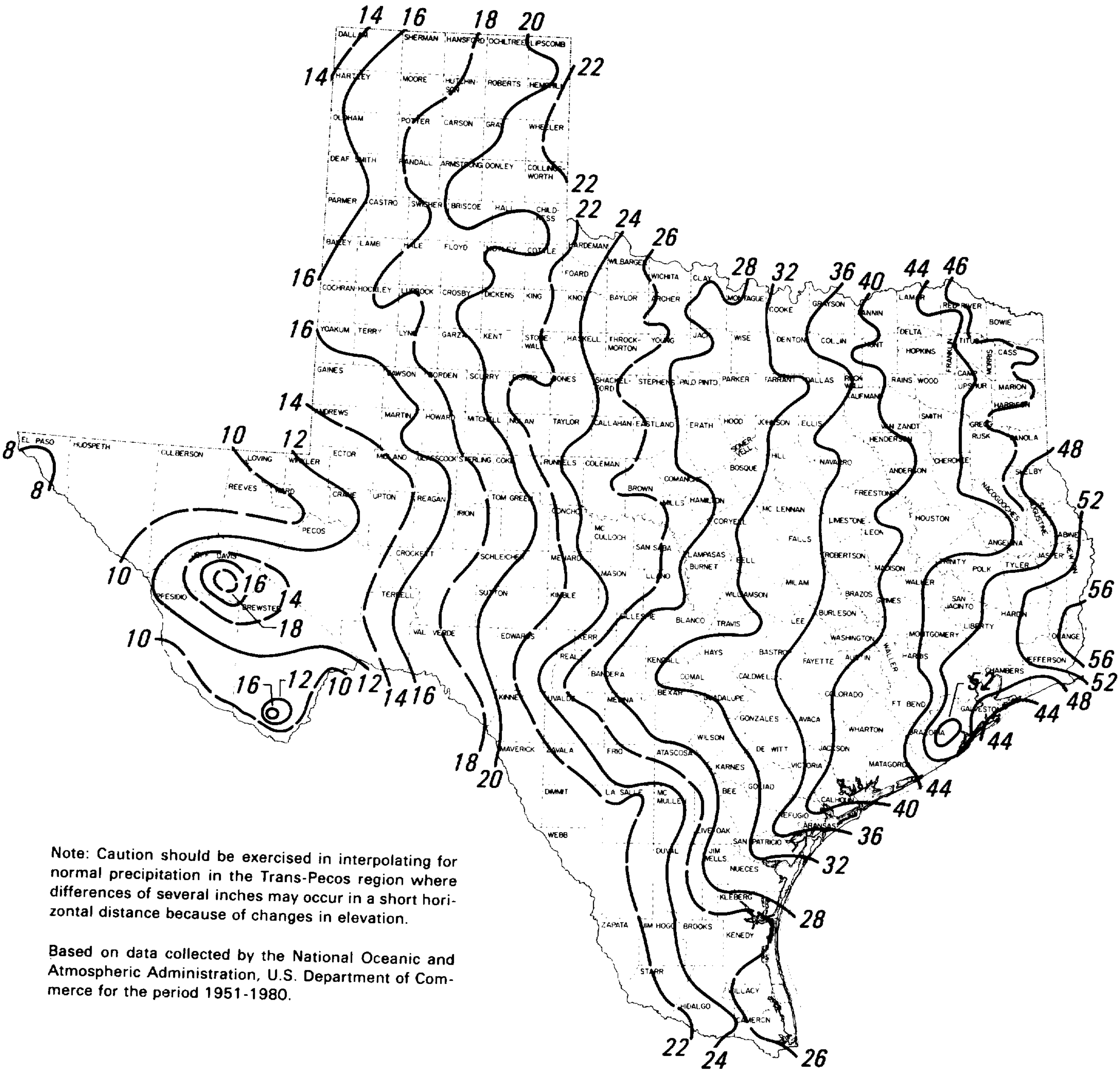
Because the Gulf is the major source of moisture for precipitation across the State, rainfall gradually decreases with greater distance westward from the Gulf. Generally, rainfall decreases from east to west across Texas at a rate of about one inch every 15 miles. For instance, average annual precipitation ranges from more than 56 inches at the eastern border to less than eight inches in the westernmost region of the Trans-Pecos (Figure II-1).

Variation in average annual rainfall is also a feature of the climate. The wettest year of this century in Texas was 1941, when there was a statewide average of more than 42 inches of rain. The driest year was in 1917, with only 14 inches of rain statewide. Although an integral part of the climate, these variations are difficult to predict.

Most precipitation in Texas is in the form of rain, although some snowfall occurs in North and West Texas. The heaviest snowfall occurs in the northern High Plains, although every few years the greatest annual snowfall will occur in the Red River Valley or in the mountains of the Trans-Pecos. Rarely is the snowfall ever substantial enough to contribute significantly to the quantities of water supplies in the State.

Drought

Drought is also a feature of the climate, during which there are long periods of time having little or no precipitation. Because it occurs at random, there is no predictable cycle of drought in Texas. The water supply is directly related to drought conditions, since the pattern of rainfall is interrupted and the loss and use of water is increased with sustained, higher temperatures. At least 14 significant periods of drought of varying severity and geographical extent have occurred in Texas in the 20th century. The most severe drought on record occurred during the period 1950-1956.Beginning in the western part of the State, it spread across the remainder of Texas until about 94 percent of Texas' 254 counties was classified as disaster areas at the end of 1956. Another drought, nearly as severe as that in 1950-1956, began in 1916 and lasted three years.



Note: Caution should be exercised in interpolating for normal precipitation in the Trans-Pecos region where differences of several inches may occur in a short horizontal distance because of changes in elevation.

Based on data collected by the National Oceanic and Atmospheric Administration, U.S. Department of Commerce for the period 1951-1980.

Figure II-1. Normal Annual Precipitation (Inches)

Because drought reduces the available water supply and increases the consumption requirements from water in storage, the water supply entities of Texas must be prepared to store and deliver sufficient quantities of suitable quality water to meet regular needs through the drought cycle. Management for drought conditions is done by establishing dependable water supplies through the installation of additional wells for immediate use or by constructing surface water storage facilities in which floodwater of high precipitation periods is stored for future use.

Hurricanes

Like drought, hurricanes are a facet of the climate and affect the quantity of water supplies where these occur. Tropical cyclones, particularly tropical storms and hurricanes, are a perennial threat to the Texas Gulf coastal region during the summer and autumn. Virtually all of the tropical cyclones that affect the Texas coast originate in the Gulf of Mexico, Caribbean Sea, or in other parts of the North Atlantic Ocean. Although the hurricane season in Texas extends from June to October, tropical cyclones are most frequent in August and September. These infrequently affect the Coast before mid-July or after mid-October. Hurricanes contribute large quantities of precipitation in addition to producing high winds, significant storm tides, and usually result in significant property damage and loss of life.

Temperature

Unlike precipitation, the average annual temperature decreases with increasing latitude. This change is most pronounced in the western half of the State which is influenced by drier, continental air, whereas the eastern half is influenced by moist, Gulf air. As a result of the differences in moisture, there are higher average annual high temperatures in the west, and this directly affects evaporation rates and the quantities of water required for people and economic activity. The relatively greater moisture content of the Gulf air in the eastern half acts to moderate the affects of heating.

Average annual temperature ranges from 53°F in the northwestern edge of the High Plains to 74°F along the Rio Grande in the southernmost section of the State. Except in the Trans-Pecos and along the eastern edge of the Edwards Plateau, where physiography plays an important role in the spatial variation of temperature, mean annual temperatures generally increase from north to south. Usually, January is the coldest month of the year, while July and August are the warmest.

Evaporation

Evaporation is a function of temperature and significantly affects the quantity of water in storage. Evaporation is a continuous process, even in the more humid sections of the State, but rates of evaporation vary considerably in the State. Mean annual net evaporation rates vary from zero inches in East Texas near the Sabine River to approximately 100 inches in the Trans-Pecos, near El Paso. While evaporation is largely offset by rainfall in the eastern part of the State, it is not offset in the western part of Texas because rainfall is much less. Lake surface evaporation rates are uniform moving from north to south across the State.

Maximum evaporation occurs throughout the State during the summer months, while the least evaporation usually takes place in winter. During wet years, when water is plentiful, net lake surface evaporation rates are low. During years of drought, evaporation from lakes and transpiration rates of vegetation increase and more rapidly deplete water supplies. Evaporation losses are an important consideration in reservoir design and in the volume of reservoir storage to meet water supply requirements in years of drought.

Physiography

The physiography of Texas affects the variation and distribution of precipitation. Areas of the State in the higher elevations have a cooler, drier climate because they are not as affected by the general circulation of moist, Gulf air that is characteristic for the lower, easternmost elevations of the State.

Texas is a part of four major physiographic subdivisions of North America—the Gulf Coastal Forested Plains, the Great Western Lower Plains, the Great Western High Plains, and the Rocky Mountain Region. Moreover, there are three major plains divisions within the State—the Staked Plains, or Llano Estacado, the North Central Plains, and the Gulf Coastal Plain (Figure II-2). Elevation increases from the Gulf Coastal Plain westwards through the Staked Plains.

The Staked Plains, reaching an elevation of about four thousand feet above sea level in the Panhandle, is a part of the Great Western High Plains, an alluvial mantle extending east from the Rocky Mountains. In the Panhandle, and to a line marked by the caprock escarpment, the Staked Plains is known as the High Plains of Texas, characteristically level, relatively treeless, and semi-arid. Below the caprock escarpment that delineates the High Plains is the

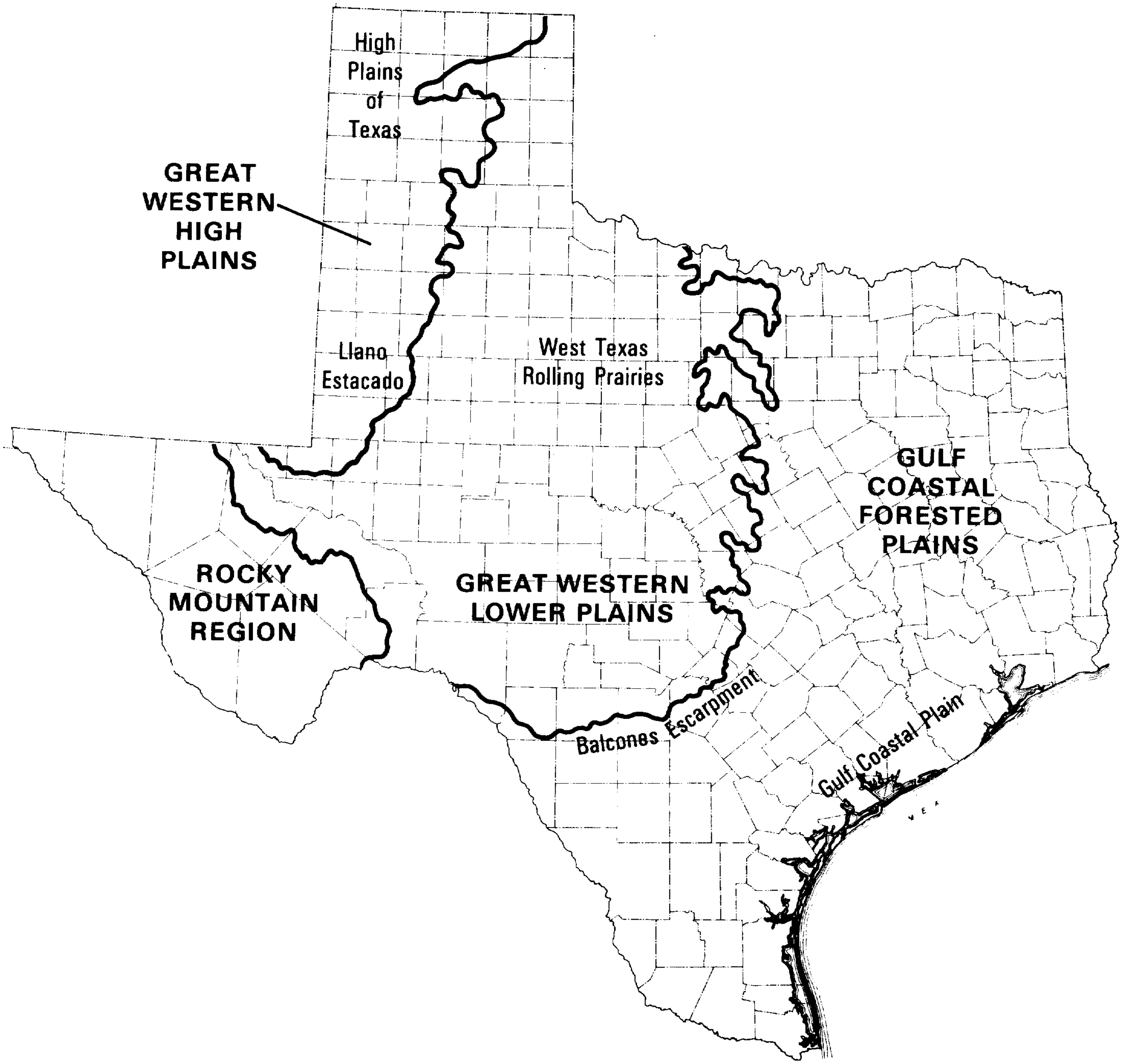


Figure II-2. Major Physiographic Regions of Texas

Edwards Plateau, roughly 35 thousand square miles of limestone, deeply dissected and rapidly drained, and ranging in elevation from about 2,600 feet above sea level in the west to about 700 feet in the east.

The Balcones fault system spreads across Central Texas from Del Rio on the Rio Grande, eastward to San Antonio and northeastward to Austin. This fault marks the boundary between the lowland, coastal plains and the upland plains and plateaus. Above the fault system, on the Edwards Plateau and through Central Texas, streams have eroded and cut through the land surface, while below the fault escarpment sediment loads have been released from which deep soils have been formed.

The North Central Plains is the southern extension of the Great Plains and includes the West Texas Rolling Prairies, Grand Prairie, and East and West Cross Timbers regions. Level to rolling topographically, the area is a typical prairie environment, with the occurrence of timber increasing to the east.

The Balcones fault system marks the western edge of the Texas Gulf Coastal Plain, a part of the Coastal Plains extending along the Gulf from the Atlantic to beyond the Rio Grande. Rising from sea level at the coast to around 550 feet above sea level below the fault system, the area is topographically rolling to hilly. It is marked by a heavy growth of pine and hardwood in East Texas. While in the more arid west, vegetation consists largely of post oak, further west, the prairies are treeless.

Ground Water

Aquifers presently supply 61 percent of the water used in Texas. An aquifer is a formation, group of formations, or part of a formation that is water-bearing. In the past, municipalities, industries, and irrigators, as well as rural inhabitants, have generally turned to this resource to satisfy water demands because of: (1) the widespread geographical occurrence of aquifers, (2) the absence of sufficient surface-water supplies or lack of facilities for storing and distributing available supplies, and (3) the relatively low costs of developing and pumping this resource as compared to the costs of constructing storage and treatment facilities for surface-water supplies in areas where both surface water and ground water exist.

Major Aquifers

During the period 1957 through 1962, the Board of Water Engineers, in cooperation with the U.S. Geological Survey, conducted reconnaissance investigations of the ground-water resources of the State. Data collected from these studies, as well as previous and subsequent investigations, resulted in the delineation of the major and minor aquifers in Texas (Figures II-3 and II-4).

A major aquifer is defined herein as one which yields large quantities of water in a comparatively large area of the State. These include the High Plains (Ogallala), Alluvium and Bolson Deposits, Edwards-Trinity (Plateau), Edwards (Balcones Fault Zone), Trinity Group, Carrizo-Wilcox, and Gulf Coast Aquifers. Collectively, these aquifers supply most of the ground water used in the State.

High Plains (Ogallala) Aquifer

The Ogallala Formation of Pliocene age occurs at or near the surface over much of the High Plains area of northwest Texas. The formation consists of alternating beds of silt, clay, sand, gravel, and caliche, reaching a maximum known thickness of more than 900 feet in southwestern Ochiltree County. The High Plains aquifer consists primarily of the Ogallala Formation, and includes all water-bearing units, mainly Cretaceous and Triassic sediments, with which it is in hydraulic continuity. However, the Canadian River has cut through the formation dividing it into two parts, the North Plains and the South Plains.

The zone of saturation in the aquifer ranges in thickness from only a few feet to more than 500 feet. The thickest saturated sections occur in the northeastern part of the South Plains. In the large irrigation area north and west of Lubbock, the saturated interval generally ranges between 100 and 300 feet. South of Lubbock, the saturated zone is generally between 50 and 150 feet thick.

Depth to water in the aquifer ranges between 100 and 200 feet throughout much of the South Plains, but, depths to water commonly exceed 300 feet in parts of the North Plains. Yields of wells range from less than 100 gpm (gallons per minute) to more than 2,000 gpm, averaging about 500 gpm.

Small quantities of natural recharge to the High Plains (Ogallala) Aquifer result from precipitation on the land surface and underflow from that part of the aquifer in New Mexico. Water moves slowly through the formation in a generally southeasterly direction toward the eastern escarpment of the High Plains.

Alluvium and Bolson Deposits

Deposits of alluvium occur in many parts of Texas, and generally consist of alternating and discontinuous beds of silt, clay, sand, and gravel of recent geologic age. In some

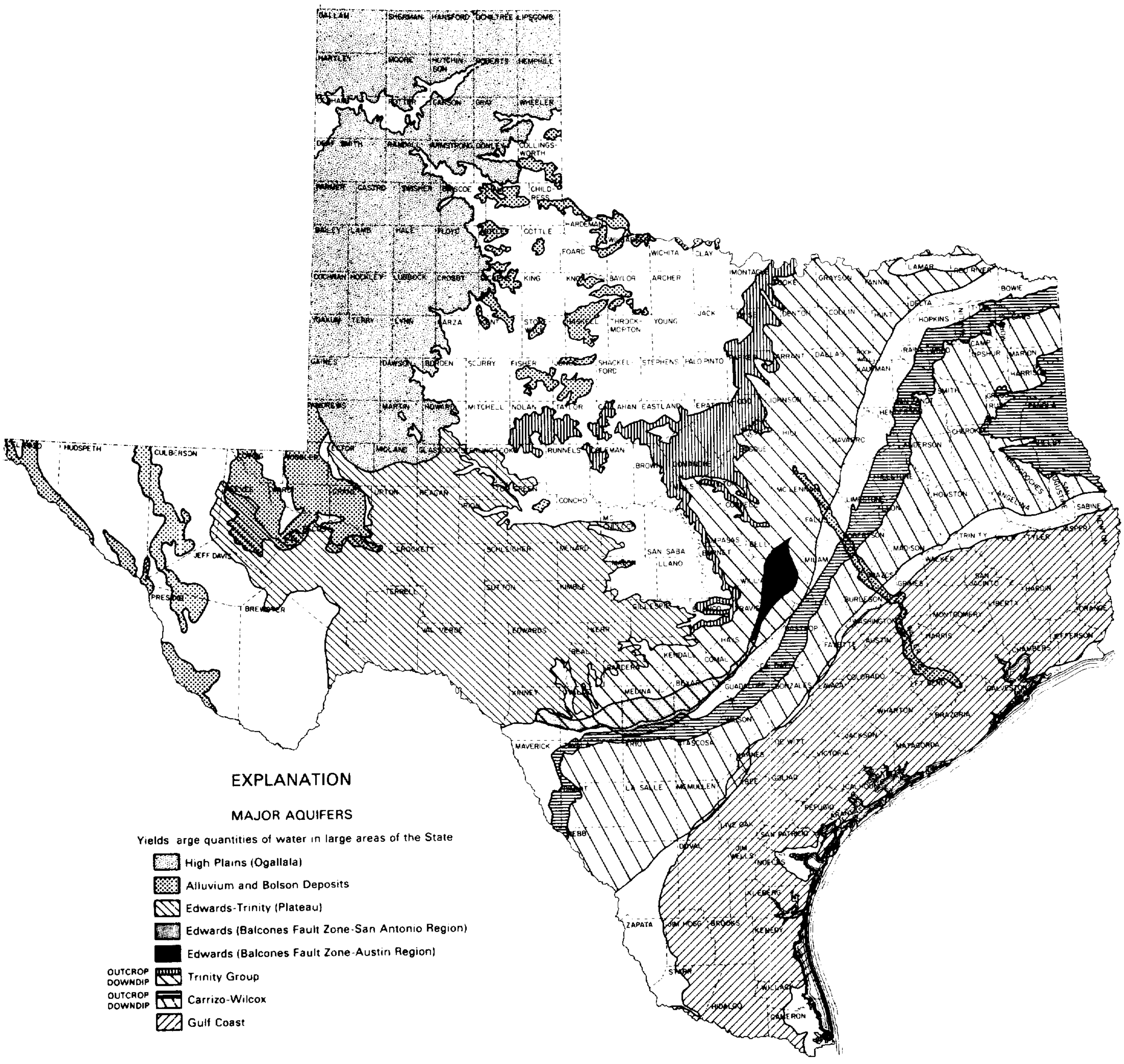


Figure II-3. Major Aquifers

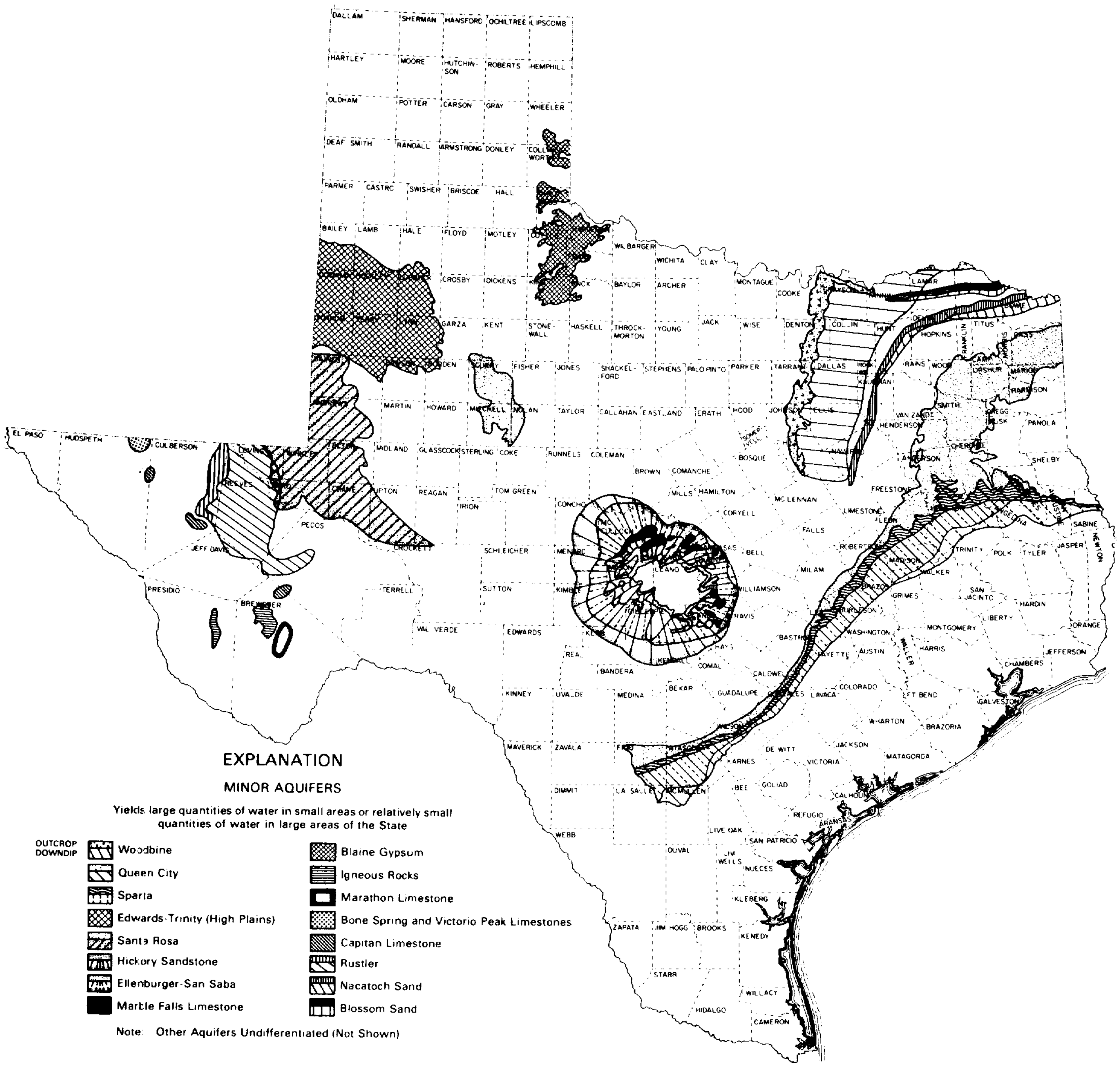


Figure II-4. Minor Aquifers

areas, these deposits contain comparatively large volumes of water, and the five largest and most productive of these local aquifers collectively make up a major aquifer in the Trans-Pecos area.

In the El Paso area and the El Paso Valley, alluvium and bolson deposits ranging to more than 9,000 feet thick contain fresh water to depths of about 1,200 feet. Large-capacity wells completed in this aquifer commonly yield between 1,000 and 1,500 gpm, supplying water for irrigation and municipal use.

Alluvium and Bolson deposits extending from northeastern Hudspeth County to northern Presidio County supply large volumes of water for irrigation. Large-capacity wells completed in the aquifer yield up to 2,500 gpm. At the present rate of pumpage, however, it is projected that these supplies will be largely depleted before the year 2020.

In the upper part of the Pecos River drainage system in Texas, deposits of alluvium ranging up to 1,500 feet or more in thickness yield large volumes of water used principally for irrigation. This aquifer also supplies municipal and industrial water needs in this region, including supplies for the Cities of Monahans and Pecos. Legal rights to the water in a large volume of the aquifer in northwestern Winkler and northeastern Loving Counties have been acquired by the City of Midland as a potential source of future supply for that city; however, these supplies can furnish only a part of Midland's projected future water needs.

Isolated areas of alluvium (principally erosional remnants of the Seymour Formation) furnish domestic, municipal, and irrigation supplies to areas of North and West Central Texas. These local aquifers in the upper Red and Brazos River Basins vary greatly in thickness, but in most areas the saturated interval is less than 100 feet. Pumpage at times and in local areas has exceeded the rate of recharge. Yields of large-capacity wells range from less than 100 gpm to 1,300 gpm, with the average being about 300 gpm.

Along the Brazos River, between northern McLennan County and central Fort Bend County, stream-deposited alluvial material ranging from less than one mile to about seven miles wide supplies water for irrigation and other purposes. Thickness of the saturated interval in the aquifer ranges to 85 feet or more, with the maximum thickness of saturation occurring in the central and southeastern part of the aquifer.

Edwards-Trinity (Plateau) Aquifer

The Edwards-Trinity (Plateau) Aquifer underlies the Edwards Plateau and extends westward into the Trans-Pecos region of Texas. The aquifer consists of water-saturated sand and sandstone of the Trinity Group and limestone of the overlying Fredericksburg and Washita Groups of Cretaceous age. These water-bearing units range to more than 800 feet in thickness. Large-capacity wells completed in fractured and cavernous limestone locally yield as much as 3,000 gpm.

The Edwards-Trinity (Plateau) Aquifer supplies small cities and communities of the area with water. Industrial supplies are also obtained from the aquifer locally, principally for petroleum recovery. Natural discharge of water from the aquifer constitutes a substantial part of the base flow of several streams, including the Pecos, Devils, Nueces, Frio, and Llano Rivers.

Water supplies of the Edwards-Trinity (Plateau) Aquifer have proved difficult to develop, however, because of the irregular distribution of permeability in the limestone beds and the variable thickness of the lowermost sand and sandstone beds. In heavily pumped areas, water levels have declined significantly. Sustained heavy pumpage over long periods would result in substantial depletion of the base flows of streams draining the plateau, thus reducing somewhat the surface-water supplies of these river basins, and recharge to the Balcones Fault Zone Aquifer.

Edwards (Balcones Fault Zone) Aquifer

The Edwards (Balcones Fault Zone) Aquifer extends from central Kinney County east and northeast into southern Bell County. It includes the Edwards Limestone and stratigraphically associated limestone beds of Cretaceous age. Conditions favorable for the development of extensive solution channels and cavities and the consequent accumulation of large volumes of water in these formations have resulted from faulting along the Balcones Fault Zone.

This aquifer supplies municipal and industrial water to numerous cities and towns, including the total municipal supply for the City of San Antonio. Capacities of wells operated by the city are among the largest in the world, some wells yielding over 16 thousand gallons per minute each. Industrial and irrigation water supplies are also pumped from the aquifer.

Some of the largest springs in the State result from the discharge of water from the aquifer. These include Leona Springs at Uvalde, San Pedro and San Antonio Springs in San Antonio, Comal Springs at New Braunfels, San Marcos Springs at San Marcos, Barton Springs at Austin, and Salado Springs at Salado.

The aquifer is recharged partly by precipitation on the recharge zone, storm runoff which enters the recharge zone, and streams which head in the Edwards Plateau. The West Nueces, Nueces, Frio, Sabinal, Medina, and Blanco Rivers and Seco, Hondo, and Cibolo Creeks, flow across the Balcones Fault Zone, losing water into the extensive fracture system of the aquifer. Water moves rapidly through the aquifer, and the volume of water in storage and the rate of springflow change rapidly in response to rainfall. For example, the depletion of water in storage resulting from continuous heavy pumpage during the drought years 1948-1956 was almost completely restored during the wet years 1957 and 1958.

Highly saline water, containing hydrogen sulfide gas, occurs in the Edwards and associated limestone beds south of the heavily pumped areas. The possibility of saline water intrusion and the necessity to maintain springflow at adequate levels for environmental and recreational purposes are constraints upon increased pumping from the aquifer, particularly during drought periods, as water needs increase.

Trinity Group Aquifer

The Trinity Group Aquifer extends over a large area of North and Central Texas. The thickness of the aquifer ranges from a few feet along its western edge to more than 1,200 feet in the eastern part. Yields of large-capacity wells range up to several thousand gpm. In thin sections of the aquifer, where water is withdrawn principally for irrigation and domestic use, most wells yield less than 100 gpm.

The Trinity Group Aquifer has been intensively developed for municipal and industrial water supply in the Dallas-Fort Worth area and formerly provided much of the municipal water supply for the City of Waco. In these heavily pumped areas, significant reduction in artesian head has occurred, thus lowering pumping levels and increasing pumping costs.

Carrizo-Wilcox Aquifer

The Carrizo-Wilcox Aquifer, one of the most extensive in Texas geographically, furnishes water to wells in a wide belt extending from the Rio Grande northeastward into Arkansas and Louisiana. The aquifer consists of hydrologically connected sand, sandstone, and gravel of the Wilcox Group and overlying Carrizo Formation.

The Carrizo-Wilcox Aquifer is recharged by precipitation and storm runoff on the outcrop areas and by streams which cross the outcrop area. The water-bearing beds dip beneath the land surface toward the Gulf, except in the East Texas structural basin where the formations form a trough and are exposed at the surface on both sides of the trough's axis. The net thickness of the aquifer ranges from a few feet in the outcrop to more than 3,000 feet downdip.

Water in the Carrizo-Wilcox Aquifer is generally under artesian pressure, and flowing wells are common in areas of low elevation. However, in heavily pumped irrigation areas, such as the Winter Garden area, and in municipal and industrial well fields, such as those north of Lufkin, water levels have declined and pumping costs have increased significantly.

Yields of wells vary widely, but yields of more than 1,000 gpm from large-capacity wells are common, and some wells yield as much as 3,000 gpm. Usable quality water occurs at greater depths (up to about 5,300 feet) than in any other aquifer in the State.

Water from the Carrizo-Wilcox Aquifer is used for irrigation in the Winter Garden area and for municipal and industrial use in Angelina and Nacogdoches Counties. The municipal and industrial use in these two counties has exceeded 20 million gallons of water per day.

Gulf Coast Aquifer

The Gulf Coast Aquifer underlies most of the Coastal Plain from the Lower Rio Grande Valley northeastward into Louisiana, extending about 100 miles inland from the Gulf. The aquifer consists of alternating clay, silt, sand, and gravel beds belonging to the Catahoula, Oakville, Lagarto, Goliad, Willis, Lissie, and Beaumont Formations, which collectively form a regional, hydrologically connected unit.

Fresh water occurs in the aquifer to depths of more than 3,000 feet, and large quantities of water are pumped for municipal, industrial, and irrigation use. In the Houston metropolitan area, from 300 to 350 million gallons is pumped daily for municipal and industrial use. Large-capacity wells yield as much as 4,500 gpm in this area. In the central and southern parts of the coast, the net thickness of water-bearing zones in the aquifer decreases, and yields of wells are somewhat less, although locally wells may yield as much as 3,000 gpm.

The aquifer is recharged by precipitation on the surface and seepage from streams crossing the outcrop area. The rate of natural recharge is estimated to be sufficient to sustain present levels of pumpage from the aquifer; however, in heavily developed areas withdrawals must be limited to quantities equal to local area recharge, otherwise the water table will be lowered further and additional subsidence will occur. In some areas where the aquifer is essentially undeveloped, substantial volumes of potential recharge are rejected. Problems related to withdrawal of water from the Gulf Coast Aquifer are: (a) land-surface subsidence, (b) increased chloride content in the water of the southwest portion of the aquifer, and (c) salt-water encroachment along the coast.

Minor Aquifers

The 16 minor aquifers in Texas are important and in some areas are the only sources of water supply. Minor aquifers are defined as those which yield large quantities of water in small areas or relatively small quantities of water in large areas of the State (Figure II-4).

Minor aquifers are the Woodbine, Queen City, Sparta, Edwards-Trinity (High Plains), Santa Rosa, Hickory, Ellenburger-San Saba, Marble Falls, Blaine, Igneous Rocks, Marathon, Bone Spring and Victorio Peak, Capitan, Rustler, Nacatoch, and Blossom. Bonham, Brady, Bryan, Burnet, Carrollton, Commerce, Crockett, Fredericksburg, Italy, and Kermit are examples of cities depending partially or entirely upon minor aquifers for a water supply.

Availability of Water

Current appraisals indicate that about 430 million acre-feet of ground water is recoverable from storage in the aquifers of Texas, using conventional water-well technology (Table II-1). Estimated average annual recharge to Texas aquifers is 5.3 million acre-feet. Annual ground-water use in recent years has ranged from 10.8 to 13.8 million acre-feet.

The quantities of water that can be obtained from each aquifer per unit time in the future, in this case average quantities per year, are the sum of average annual recharge and the quantities that can be withdrawn annually from storage. The former is determined by precipitation, aquifer characteristics, vegetative cover, and other factors. The latter, annual withdrawals from storage, are determined by annual demands for water, physical properties of each aquifer that affect water yield, the number and size of water wells, and the length of time wells are pumped. Projections of annual ground-water withdrawals from most aquifers for the period 1983 through 2029 were based upon estimates of annual water demands, recharge, projected demand for water in future years, and specific physical limitations of each aquifer (Table II-1). For the Gulf Coast Aquifer, pumpage estimates were limited to that quantity which could be withdrawn annually without unacceptable levels of subsidence. For the Edwards (Balcones Fault Zone) and most other aquifers, annual pumpage is estimated at the annual recharge rate (Table II-1). For the Ogallala, Bolson, and some alluvium aquifers of Western Texas, average annual recharge is quite low and average annual demand exceeds recharge manyfold. Thus, withdrawals to meet annual needs are from the stocks or reserves that have been accumulating in storage over long periods of time. The average annual rate of withdrawal can be varied widely, thus lengthening or shortening the period of time the aquifers can serve as a source of water supply in the future. The estimates of annual withdrawal from these aquifers are based upon data about the quantity of withdrawal in the recent past and projected future water demands in the local areas that they serve. It is emphasized that the annual quantities of ground-water supply that could be available from aquifers having water in storage can vary significantly from the estimates presented here, if water users' demands differ from those used as a basis for these computations; i.e., if annual overdraft is increased or decreased from that estimated herein. This, of course, can only be done until such aquifers are depleted, at which time the maximum average annual supply would be equal to average annual recharge.

Quality of Water

The quality of water in the major and minor aquifers of Texas varies according to location, type, and lithologies of the individual aquifers. In the eastern portion of the State usable-quality water generally occurs at greater depths than in other areas of Texas. Isolated aquifers, such as the High Plains (Ogallala), Edwards-Trinity (Plateau), and certain of the Alluvium aquifers, tend to have water which lies within a specific quality range. Aquifers that are overlain by successively younger formations contain water in which the amount of dissolved solids increases at greater depths. The chemical quality of ground water is largely dependent on the lithology of the aquifer; limestone aquifers contain water high in concentrations of calcium, magnesium, and bicarbonate; aquifers containing large amounts of gypsum contain water high in concentrations of calcium and sulfate; and in aquifers composed primarily of sand and gravel the quantity of dissolved solids generally is considerably less than in other types of aquifers.

The quality of ground water in some areas is thought to be threatened by disposal of wastes, in other areas by increases in mineralization as a result of recycling of irrigation return flows and seepage losses, and in some areas by saline water intrusion caused by modification of the natural hydrodynamics of aquifers as water is withdrawn.

Major Aquifers

The High Plains (Ogallala) Aquifer contains water generally ranging between 300 and 1,000 milligrams per liter (mg/l) of dissolved solids, of which calcium, magne-

Table II-1. Estimates of Ground-Water Supplies With Projections of Ground-Water Withdrawals, High Case, 1990-2030.

Aquifer	Approximate Annual Recharge	Approximate Quantity Recoverable From Storage As of 1980	Projected Average Annual Ground-Water Supplies (Annual Recharge and Storage Depletion)[1]					Approximate Remaining Quantity Recoverable from Storage 2031
			1990	2000	2010	2020	2030	
Major								
High Plains, (Ogallala)	438,900	385,480,700	6,543,400	8,219,500	7,659,800	6,015,000	4,575,600	152,512,900
Alluvium and Bolson Deposits	434,000	32,265,500	952,100	989,700	1,027,500	1,016,900	469,900	3,014,200
Edwards-Trinity (Plateau)	776,000	[6]	776,000	776,000	776,000	776,000	776,000	[6]
Edwards (Balcones Fault Zone)[2]	438,700[3]	[6]	438,700	438,700	438,700	438,700	438,700	[6]
Trinity Group	95,100	795,500	110,100	110,100	110,100	110,100	95,100	0
Carrizo-Wilcox	644,900	9,909,200	828,700	828,700	828,700	828,700	644,900	0
Gulf Coast	1,229,800[4]	[6]	1,229,800	1,229,800	1,229,800	1,229,800	1,229,800	[6]
Minor								
Woodbine	26,100	[6]	26,100	26,100	26,100	26,100	26,100	[6]
Queen City	682,100	[6]	682,100	682,100	682,100	682,100	682,100	[6]
Sparta	163,800	[6]	163,800	163,800	163,800	163,800	163,800	[6]
Edwards-Trinity (High Plains)[5]	—	886,000	—	—	—	—	—	886,000
Santa Rosa	23,500	[6]	23,500	23,500	23,500	23,500	23,500	[6]
Hickory Sandstone	52,600	[6]	52,600	52,600	52,600	52,600	52,600	[6]
Ellenburger-San Saba	29,400	[6]	29,400	29,400	29,400	29,400	29,400	[6]
Marble Falls Limestone	26,400	[6]	26,400	26,400	26,400	26,400	26,400	[6]
Blaine Gypsum	142,600	[6]	142,600	142,600	142,600	142,600	142,600	[6]
Igneous Rocks	10,700	[6]	10,700	10,700	10,700	10,700	10,700	[6]
Marathon Limestone	18,300	[6]	18,300	18,300	18,300	18,300	18,300	[6]
Bone Spring and Victorio Peak Limestones	17,000	[6]	17,000	17,000	17,000	17,000	17,000	[6]
Capitan Limestone	12,500	375,000	19,400	19,400	19,400	19,400	12,500	0
Rustler	4,000	[6]	4,000	4,000	4,000	4,000	4,000	[6]
Nacatoch Sand	1,500	[6]	1,500	1,500	1,500	1,500	1,500	[6]
Blossom Sand	700	[6]	700	700	700	700	700	[6]
Permian and Pennsylvanian (undivided)	2,400	[6]	2,400	2,400	2,400	2,400	2,400	[6]
TOTALS	5,271,000	429,711,900	12,099,300	13,813,000	13,291,100	11,635,700	9,443,600	156,413,100

SOURCE: Texas Department of Water Resources.

[1] Estimated withdrawals for the projected high case of water demands. Estimates shown here are annual rates of supply available at each decadal point in time. Estimates of annual supply rates for intervening years can be obtained by interpolating between decadal points.

[2] Includes San Antonio and Austin Regions.

[3] The estimate provides for spring flow at San Marcos Springs and protection against water quality deterioration.

[4] The estimate provides for minimum land-surface subsidence.

[5] Part of this aquifer's availability is included in the High Plains (Ogallala) Aquifer.

[6] Not determined due to lack of sufficient data.

sium, and bicarbonate are the principal constituents. The water is hard but suitable for most uses. Comparatively small, widely distributed areas of saline water occur, principally associated with large saline playas in the southeastern part of the South Plains where the water table is shallow. In these areas, solution of salt deposits and evaporation are largely responsible for the increase in the salinity of the ground water.

The Alluvium and Bolson Deposits Aquifer occurs in many parts of Texas with water quality varying correspondingly. In the Trans-Pecos area most of the water contains between 1,000 and 4,000 mg/l of dissolved solids. The quality of ground water in North Central Texas varies widely but generally ranges from less than 500 to more than 2,500 mg/l of dissolved solids. High concentrations of nitrate, which are considered to be undesirable for human consumption, occur in this area. Salinity of the ground water has increased in some of the heavily pumped areas. The chemical quality of water in the Brazos River alluvium varies widely, even within short distances, and in many areas concentrations of dissolved solids exceed 1,000 mg/l.

The Edwards-Trinity (Plateau) Aquifer contains water that varies widely in concentrations of dissolved solids. The water is generally hard with the principal dissolved solids being calcium, magnesium, and bicarbonate. The salinity of the ground water generally increases toward the west, where the aquifer is overlain by younger geologic formations.

The Edwards (Balcones Fault Zone) Aquifer contains water with an average dissolved solids concentration of about 300 mg/l. Toward the west, the water is generally somewhat more mineralized. The water contains calcium, magnesium, and bicarbonate, and consequently is hard. This aquifer is extremely sensitive to pollution in recharge areas due to lack of soil cover and almost immediate response to recharge.

The Trinity Group Aquifer's concentration of dissolved solids generally does not exceed 500 mg/l throughout its western extent. Toward the east, where the water-bearing zones become deeply buried, usable quality water occurs to depths of about 3,500 feet, and dissolved solids concentrations range from 500 mg/l to about 1,500 mg/l near the fresh-saline water interface. In some areas, improper well-completion methods and failure of well casings have allowed saline water in overlying beds to enter the fresh water-bearing zones.

The Carrizo-Wilcox Aquifer yields fresh to slightly saline water throughout most of its extent in Texas. Water in the deeper, heavily pumped areas of the aquifer contains sodium and bicarbonate and is, therefore, comparatively soft. However, hydrogen sulfide and methane gas occur locally, and iron, frequently in objectionable quantities, is common throughout much of the northeastern extent of the aquifer. Where geologic formations overlying the aquifer contain saline water, as in the Winter Garden area, improper water well completion practices, failure of well casings from corrosion, and decline in the artesian head have resulted in interformational leakage of saline water.

The Gulf Coast Aquifer generally yields water ranging from 500 to 1,500 mg/l dissolved solids. Throughout most of the eastern part of the aquifer the water is low in dissolved solids, generally containing less than 500 mg/l. Sodium and bicarbonate are commonly the principal constituents, and the water is comparatively soft. The presence of iron and dissolved gases and slight acidity of the water are local problems that frequently require appropriate pretreatment. Water generally is more saline in the southern part of the aquifer, and in some areas highly saline water overlies the fresh water and also underlies the aquifer at relatively shallow depth. In the Lower Rio Grande Valley, water pumped from the aquifer for irrigation and municipal use contains between 1,000 and 1,500 mg/l of dissolved solids.

Minor Aquifers

Minor aquifers contain some of the same minerals found in major aquifers, such as calcium, magnesium, bicarbonate, sodium, chloride, sulfate, nitrate, iron, and dissolved gases such as hydrogen sulfide. The Woodbine, Edwards-Trinity (High Plains), Ellenburger-San Saba, Marble Falls, Marathon, Bone Springs and Victorio Peak, Capitan, and Rustler are all limestone aquifers, containing water which is hard and high in calcium, magnesium, and bicarbonate minerals. Additionally, the Edwards-Trinity, Bone Springs and Victorio Peak, Capitan, and Rustler aquifers have high concentrations of chloride and sulfate ions in some areas.

The Woodbine, Queen City, Sparta, Santa Rosa, Hickory, Nacatoch, and Blossom are sandstone aquifers and contain chloride and sulfate ions. The Queen City and Hickory contain high concentrations of iron. Hydrogen sulfide gas is abundant in the Queen City Aquifer. Additionally, the Woodbine is generally high in concentrations of chloride and sulfate ions.

Water from the Blaine Aquifer is high in dissolved solids, chiefly calcium and sulfate.

Protection of Ground-Water Quality

Much of the ground-water resources in Texas is vulnerable to quality degradation from a variety of man's activities unless consideration is given to protecting it. To establish quality criteria, measures of chemical, physical, and bacterial constituents must be specified, as well as standard methods for reporting results of water analyses.

The Department assists the Railroad Commission of Texas by making recommendations to the oil and gas industry and the Commission for the protection of usable-quality ground water during the exploration for and production of oil, gas, and other minerals, as well as during the disposal of oil-field brine by injection into subsurface formations. Additionally, recommendations are made to the Railroad Commission for the protection of usable-quality ground water in surface mining and in-situ gasification operations regulated by the Commission.

The Department issues permits to regulate the disposal of municipal, industrial, and mining wastes by underground injection to protect the quality of ground and surface water. The agency also regulates sulfur and salt solution mining, as well as uranium leach mining operations. The Water Well Drillers Board is provided administrative, technical, and legal assistance by the Department. This is accomplished by maintaining records of licensed water-well drillers, conducting investigations of alleged violations of the Texas Water Well Drillers Act, and making recommendations for the proper plugging of abandoned water wells. The Department makes investigations of alleged ground-water contamination or conditions which might cause or threaten to cause deterioration of the quality of underground water in the State. A statewide ground water quality monitoring network is maintained in which standard chemical analyses are made periodically to determine changes in quality.

Surface Water

State waters are defined by Texas water law as the ordinary flow, underflow, and tides of every flowing river, natural stream, and lake; and of every bay or arm of the Gulf of Mexico; and the storm-water, floodwater, and rainwater of every river, natural stream, canyon, ravine, depression, and watershed in the State. For the purposes of water planning and administration, surface-water resources are considered to include the waters flowing in Texas streams, as well as those waters in interstate streams which are allocated to Texas under interstate compacts and international treaties.

River Basins

Texas has 15 river basins and 8 coastal basins. Each basin is designated as a planning area for purposes of calculating in-basin water supplies and for projections of in-basin water requirements for the 50-year foreseeable future. Also, since Texas river basins cross climatic zones as they traverse the State in a northwest to southeasterly direction, the individual basins are further subdivided into 43 relatively homogeneous zones (Figure II-5).

Reservoirs

There are 184 major reservoirs in Texas, each with a capacity of 5,000 acre-feet or greater. In addition, 5 reservoirs are under construction and when completed will bring the total number of reservoirs to 189. Of this total, 148 or 80 percent will have been developed without federal funds. Conservation storage in the 189 reservoirs is estimated to be about 32.3 million acre-feet of water (includes only Texas share of interstate and international reservoirs), with an additional 17.5 million acre-feet of flood control storage (see Part III). However, the estimated dependable water supply in year 2,000 from the State's major water supply reservoirs is about 11 million acre-feet annually. This volume represents the maximum safe yield which can be withdrawn each year through an extended drought.

Hydrology

Atmospheric moisture precipitates to earth in the form of rain, sleet, or snow. Upon reaching ground surface, the precipitation can evaporate back to the atmosphere, penetrate the soil layers of the root zone where plants capture it for use and through transpiration return it to the atmosphere, penetrate the soil layers to the water table and become part of the ground waters, or run off the land surface into watershed drainages which contribute to streamflows. Thus, the surface waters of Texas are primarily derived from direct rainfall runoff, plus spring flows emanating from the State's aquifers.

The runoff from rainfall has averaged 52 million acre-feet per year in Texas over the 1941 through 1980 historical period, but was only 23 million acre-feet annually during the 1950 through 1956 drought interval. Approximately 50 percent of the total Texas runoff originates in the eastern quarter of the State where the average runoff rate is about 650 acre-feet per square mile. Runoff rate decreases across the State to near zero in large areas of West Texas, and, about 16 percent of the total runoff in Texas is in the coastal areas, where the possibilities for capture and use are limited because reservoir sites are generally not available in this topographically flat region. However, the runoff contributes freshwater inflows to Texas bays and estuaries which are essential to the production of fish and shellfish.

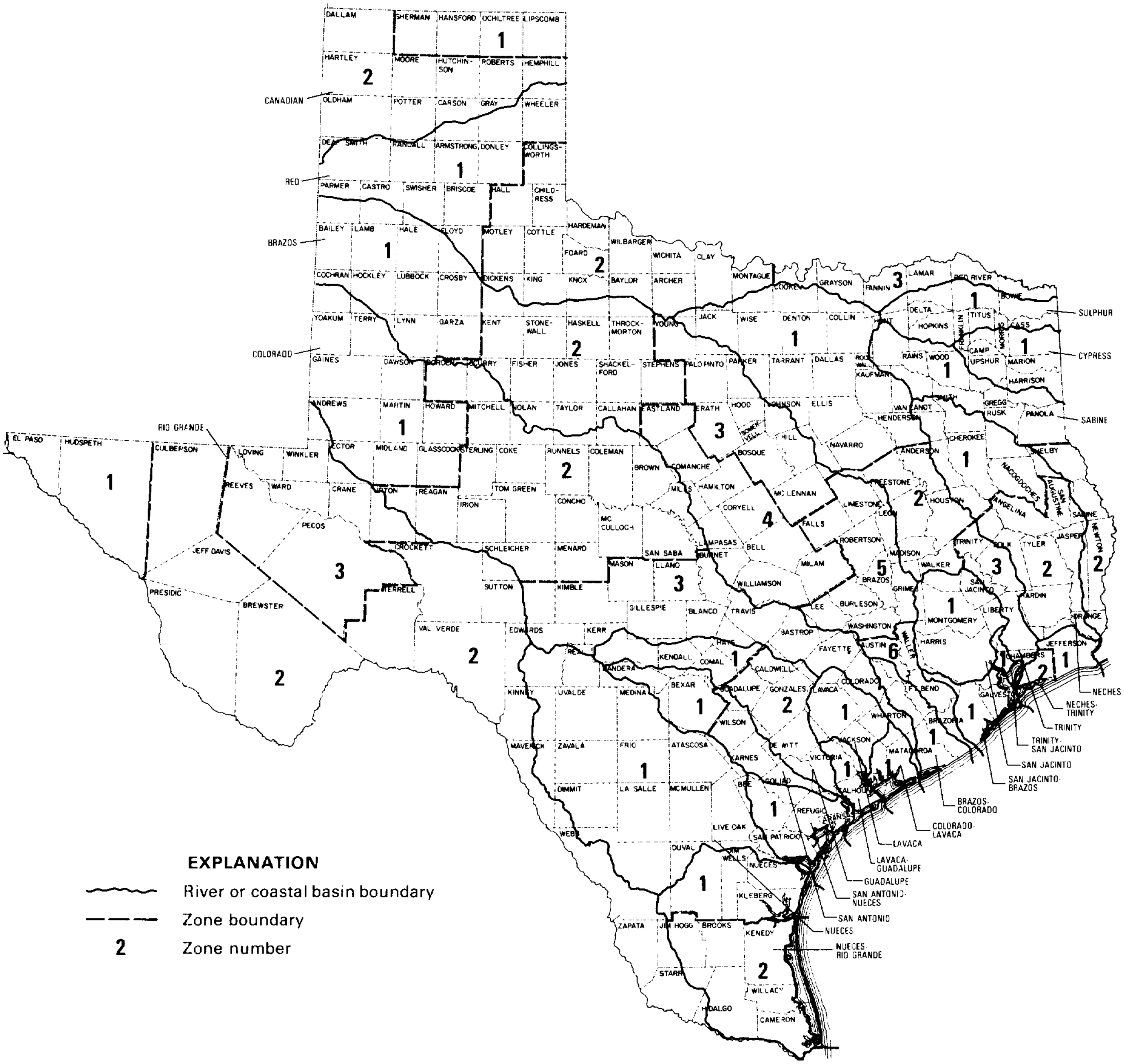


Figure II-5. River and Coastal Basins and Zones

Availability of Water

Since Texas streamflows are highly variable, and in some cases are intermittent, the requirement for dependable water supplies has necessitated the construction of reservoirs to capture and store a portion of the normal and flood flows. The quantity of water continuously available from each reservoir is referred to as the "firm yield." The firm yield of a reservoir is defined as the quantity of water that can be annually withdrawn or released from the impoundment over a period of time which spans the length of the most severe drought recorded in the catchment area. The firm yield depends on inflows to the reservoir, capacity and shape of the reservoir, evaporation and seepage, and any required outflows from the impoundment.

Firm yields of existing and potential reservoirs in each river basin are computed in an upstream to downstream order. Each reservoir in the basin is assumed to be operated over the critical drought period so as to maximize the capture of runoff from the watershed. Water spilled from upstream impoundments and return flows from upstream water users are included in the water available for downstream storage. In this way, flow depletions resulting from upstream land-use activities and instream construction of reservoir and floodwater retention structures can be considered in calculating the availability of future downstream flows.

An increasingly important component of the State waters is return flow from nonconsumptive water uses. Return flows generally originate as wastewater discharges or treated effluents from municipal, industrial, and agricultural water users. Return flow projections are essential to both determining water availability and evaluating wastewater reuse potentials. In addition, the location or spatial distribution of return flows throughout the State can have a significant impact on the future availability of surface waters in some zones of Texas river basins. Therefore, total consumptive use or reuse of State waters in some zones may not be desirable because of the resultant flow depletions in other zones.

Sedimentation

Texas streams can carry large volumes of sediment produced by erosion in the contributing watersheds, particularly during heavy rainfall and flood events. Some of this sediment is trapped in the first downstream reservoir, gradually reducing its storage capacity. Currently, storage volume for an estimated 100 years of sediment is included in the design of new reservoirs. However, it is though that improvement in overall river basin development can be realized by construction of sediment catchment basins above major water supply reservoirs, as well as by river channel stabilization, improvement in grass cover on rangelands, reforestation, and increased use of other soil conservation techniques in the contributing watersheds. Information about sediment loadings to the watercourses is useful for planning land conservation measures, designing instream structures, and analyzing the transport and deposition of some pollutants and toxic materials.

Quality of Water

The physical, chemical, and biological characteristics of water define its quality. Although there has been rapid population growth (three million people between 1970 and 1980), accompanied by increased water use in Texas, the quality of the State's surface waters has improved significantly. Much of this improvement is directly related to the Texas Water Quality Management Program and advances in wastewater treatment by industries and municipalities. The fact that these improvements have been accompanied by water-dependent State growth demonstrates that rising levels of water quality and economic activity are occurring simultaneously in Texas.

Water Quality Management Programs

The Texas Water Quality Management Program is designed to provide long-range direction and planning for the protection and improvement of the State's surface-water quality. In practice, the program is organized into seven basic components: (1) assessment of water quality problems, (2) inventory of stream water quality, (3) development of a multi-year management strategy, (4) development of detailed local and statewide work plans, (5) implementation of the work plans, (6) evaluation of progress, and (7) reassessment of the water quality program.

An important part of the water quality program involves the State's management strategy, which includes environmental goals for the next three to five years, identification of priority water quality problem areas, cost estimates for control of the problems, identification of responsible entities, and a summary of anticipated funding from federal and State sources. A major emphasis of the strategy is on solving specific water quality problems in specific locations, consistent with current State laws and applicable national laws such as the Federal Clean Water Act. Also, the Texas Department of Water Resources funds projects with water quality management and construction grants and loans that control pollution and contribute to the solution of priority problems identified in the State's strategy.

Texas water quality standards have been established for maintenance of the quality of surface waters, and as goals for water quality management under State laws and policies. These standards contain two parts: (1) general criteria applicable to all surface waters, and (2) explicit numerical criteria for water quality parameters that are applicable to specified surface waters for maintenance of identified desirable water uses. The standards pertain to water quality degradation attributable to man's activities, and not that which is related to natural phenomena. The concentrations of many dissolved and suspended surface water quality constituents are largely the result of natural geographic variations in precipitation, evaporation, geology, vegetation, and the quality of spring flows from the State's aquifers.

The general criteria apply limitations on taste and odor producing substances, radioactive materials, oil, grease, and related residues, and against conditions whereby floating debris, suspended solids, turbidity, toxic materials, nutrient concentrations, or water temperatures that would adversely affect biological species or man's use of the waters. However, the numerical criteria establish exact quantitative limits on water quality parameters such as temperature, pH (acidity), dissolved oxygen, chloride, sulfate, total dissolved solids (salts), and fecal coliform bacteria. The numerical criteria are applied to specific surface-water areas on the basis of possible uses which are deemed desirable. These uses include contact recreation, noncontact recreation, propagation of fish and wildlife, and domestic raw water supply. For example, surface-water streams and pools suitable for contact recreation, such as swimming, are not to have a logarithmic mean fecal coliform count that exceeds 200 bacteria per 100 milliliters of water; whereas, noncontact recreation waters should not exceed an average logarithmic mean fecal coliform content of 2,000 per 100 milliliters.

Another important part of the State's water quality program involves designation of Texas stream segments and the inventory of water quality in these segments on at least a biennial basis. For water quality management purposes, the 23 river and coastal basins of the State have been divided into 311 stream and coastal segments with a total 16,115 stream miles. The Texas Department of Water Resources has determined that 244 of the 311 segments comply with the applicable stream standards, or are projected to be in compliance following implementation of best practicable wastewater treatment plans by industries and municipalities (Plate 2). These segments are classified as effluent limited. However, the remaining, noncompliant segments are classified as water quality limited, because monitoring data indicate that violations of the applicable State water quality standards continue to occur or they have been placed under special Board order for more stringent treatment requirements.

The purpose of the stream segment inventory is to evaluate water quality conditions, trends, and projections of the State's surface waters, to determine whether: (1) the water quality is adequate to provide for the protection and propagation of balanced populations of fish and wildlife; (2) the water quality is suitable to allow recreation in and on the water; (3) this level of water quality can be expected by 1984; or (4) the desired water quality level can be reasonably attained at some later date. The inventory also includes an assessment of nonpoint source pollution problems and useful information on ground-water use, availability, quality, and activities which may be impacting this water resource. Basically, the inventory provides a means by which the State can assess the effectiveness of the water quality management program and develop recommendations for changes in the federally approved program. The inventory is also used in preparing state-federal water quality reports in cooperation with the U.S. Environmental Protection Agency under the Federal Clean Water Act.

As an adjunct to the State's Water Quality Management Program, waste load allocation studies are performed on each of the water quality limited segments to determine stream assimilative capacity. Another object of the studies is to determine the theoretical treatment level each discharger in a particular segment would be required to provide, in order for that segment to be brought into compliance with the State's stream standards. In addition, the waste load evaluations provide a basis for discharge permit parameters. The waste load allocations require updating and continuous study in order to assure that they remain viable and adequately serve the State's water quality management program.

Waste Discharge Programs

An essential part of the State's water quality management program involves the establishment of effluent standards for wastewaters and the issuance of waste discharge permits. Also, any activity which results in a waste discharge into the State's navigable waters requires that Texas certify to the U.S. Environmental Agency (EPA) that the discharge complies with all applicable provisions of Federal Clean Water legislation. This allows EPA to issue a National Pollutant Discharge Elimination System (NPDES) permit concurrent with the State's waste discharge permit. The Department of Water Resources has promulgated a set of effluent quality standards, required under the federal law, which are consistent with treatment classes and are necessary to meet required treatment levels. Also, specific water quality protection plans are being developed for Texas surface waters that include wastewater treatment requirements and other water quality management methods, based on information the State has collected concerning both point and nonpoint pollution sources in Texas.

In addition, Texas has initiated a Hazardous Waste Management Program that satisfies both State requirements, under the Texas Solid Waste Disposal Act, and national requirements of the Federal Resource Conservation and Recovery Act. Since federal law allows a state program to be implemented in lieu of a federal program, the Texas program is being implemented and operated by the Texas Department of Water Resources and the Texas Department of Health, with financial assistance and oversight from the U.S. Environmental Protection Agency.

Methods to Extend and to Increase Water Supplies

Additional quantities of both surface and ground water can be made available through the use of one or more existing technical and management practices. Increased water use efficiency in agriculture and industry, reduced per capita use of municipal and commercial supplies, and reduction of leakage and other forms of waste can allow existing supplies to meet the needs of a larger number of people and support larger levels of industry and agriculture. In cases where ground-water supplies are declining, water conservation can allow existing levels of water-using activities to be continued for longer periods of time than will otherwise be possible. Through more effective water conservation, present water supplies could be extended to meet some of the water supply needs of the State's growing economy. However, it is clear that water conservation cannot meet all of the growing needs for water. Thus, it will be necessary to increase the use of ground water, where this is possible, to develop additional surface water where possible, to continue the research and development of desalting and weather modification technologies, with a view toward using these methods to increase water supplies in some areas, and to consider importing water from outside the State. Each of these water management and potential water development methods are described and explained below.

Water Conservation by Individuals

Due to the fact that supplies of surface and ground water are limited in some parts of the State, demands for water are increasing, and costs of securing new supplies are rising, it is necessary for individuals to practice water conservation. In this sense, water conservation means the efficient use of water and the reduction of waste. Thus, conservation involves the use of technologies and practices to reduce per capita water use by people and quantity of water used per unit of products produced by industry and agriculture. Water conservation methods include widespread distribution of conservation information to the public, water pricing policies that encourage conservation, and the organization and operation of local area water conservation districts.

Municipal and Commercial Water Conservation

Many water conservation measures are available to reduce the quantities of water used in residential, commercial, and institutional purposes for drinking, bathing, cooking, toilet flushing, lawn watering, fire protection, swimming pools, and sanitation.

For residential water use, most water is used in the bathroom and for exterior purposes such as watering lawns and shrubbery and washing cars. While exterior water use can be reduced significantly with the use of native vegetation, in-home water use can be reduced as much as 35 percent using presently available technology. These residential conservation measures include the repair of plumbing to stop leakages, the use of low-flow shower heads, low-flush and dual flush toilets, faucet aerators and spray taps, efficient lawn watering equipment, and water-efficient landscaping. City ordinances that govern plumbing codes, lot sizes, drainage grades and slopes, and landscaping can also be used to influence the quantities of water used within a city.

Many of the water conservation techniques and practices mentioned above can also reduce water use for commercial establishments, such as office buildings and other places of work. These practices are also somewhat effective for those establishments using large quantities of water such as cafeterias, restaurants, laundries, and car washes. However, effective conservation in these types of establishments requires careful controls of water-using equipment and may require modification of production processes.

Public education and information are needed in order to change habits and behavior of the water-using public, thereby reducing waste and encouraging the use of equipment that is more water efficient. Examples of these conservation measures include shutting off faucets when shaving or brushing teeth, using dishwashers and clothes washers for only full loads, and watering lawns in the mornings or evenings to reduce losses from evaporation. Some water-efficient appliances such as dishwashers, clothes washers, low-flow shower heads, and devices to reduce the quantity of water required for toilets are available at minimal additional costs.

Industrial Water Conservation

Water conservation is being practiced by many of Texas' major water-using industries to reduce energy and water costs. Generally, water for cooling or for processing operations accounts for the large majority of industrial water use.

The quantity of freshwater used for cooling can be reduced through the substitution of air cooling devices for those requiring water or the use of saline or brackish water in place of freshwater. Furthermore, processes can be altered to reduce waste heat or apply it to other purposes to conserve energy as well as water. In addition, municipal and commercial sewage effluent can be substituted in some areas for some freshwater used for cooling. However, reuse of treated effluent by industry is somewhat limited, since a proportion of this water may be required for downstream water rights, instream flow needs, and maintenance of bays and estuaries.

Agricultural Water Conservation

Declining ground-water supplies, rising costs of pumping, and limited supplies of surface water are requiring that water conservation practices be applied within irrigated agriculture. The purposes of agricultural water conservation are to allow existing, but exhaustible, ground-water reserves to support present irrigated acreages for longer periods of time in the future, to reduce costs of production, and to the extent possible to allow growth of irrigation in future decades in order to meet growing market demands for food and fiber.

Water savings can be realized by using pipelines and concrete linings of ditches to eliminate seepage and evaporation losses common with earthen irrigation ditches. Significant reductions in water use can be achieved with the use of efficient irrigation systems; the efficiency depends on an even application of water at the proper rate and time. While sprinkler systems are more efficient than gravity application methods, drip and trickle irrigation or subirrigation reduce water use appreciably. Sprinkler systems average 70 percent efficiency, although wind is a major consideration in obtaining higher efficiency. Drip or trickle irrigation applies water to the base or root zone of each plant, using plastic tubes with small outlets near the plant. Water use is reduced because water is applied in smaller quantities, and runoff and evaporation from wet soils are eliminated. Subirrigation involves the use of perforated, small-diameter plastic pipe that is buried beneath each crop row. Like drip or trickle irrigation, subirrigation has higher capital costs than sprinkler or gravity systems.

The timeliness of water application is equally important with respect to reducing water use. Some crops can be grown under controlled stress during certain stages of growth without adversely affecting yields. Since water is applied only at critical stages, water use is reduced.

Several other conservation practices include row dams to hold water in the furrows of row crops, stubble mulch tillage, minimum tillage, and no-till planting to keep plant residue on the surface of the soil in order to reduce erosion, increase infiltration, and reduce evaporation loss. Narrow row spacing of crops and careful timing of planting dates can also reduce water use. In addition, improved varieties of plants, requiring less water and resistant to disease, are becoming available. Crops that require less water can be substituted for those having greater water requirements, when market conditions and production costs are favorable. Satisfactory weed and brush control can also reduce water use. Water is lost to plants having little or no economic value such as mesquite, saltcedar, cottonwood, and willow.

Water Reuse and Recycling

Limited water supplies and pollution control laws that require better quality wastewater discharges are encouraging the reuse and recycling of water in place of additional freshwater supplies.While recycling involves recirculating relatively clean water in internal processes, reuse concerns the further use of wastewater from external or other sources.

Currently, recycling is a common practice in all process industries in Texas. For example, in the pulp and paper industry, water is used without additional treatment for different stages in processing. Wastewater reuse is most evident in the use of treated sewage effluent for irrigation and cooling electric power generators. However, because the discharges used for reuse add to the water supply for downstream users, there are some limitations on the widespread application of wastewater reuse.

Water Pricing

It has been suggested that by increasing the price of water, the quantity used would decrease, and thus the development of new supplies could be delayed or eliminated altogether. While increased price has resulted in a reduction in the quantity of various goods and services purchased in normal markets, it is not known to what extent water prices would have to be increased in order to accomplish a given level of reduction in water use in Texas.

In the past, surface water has been available to municipal customers at a price equivalent to the amortized cost of facility construction plus the costs of maintaining and operating water supply systems; that is, water has been priced at the cost of production. In the case of water supply from ground-water sources, the cost to customers also includes a component to repay costs that have been incurred to secure water rights. However, pricing policies vary among systems. Most systems charge a fixed price per month for a given quantity of water with a declining price for additional quantities, while for others, a price is charged for a minimum quantity with an increasing rate for additional quantities. The latter policy also has been used to discourage water use during peak demand, usually during summer months. Thus, several pricing options are available to individual system operators, if price is to be chosen as a local area conservation tool.

Conservation Institutions

In Texas, some local water resources associations were organized as a mechanism for the efficient use, development, protection, and management of surface- and ground-water resources. These include underground water conservation districts, whose purpose is to prevent waste, protect the quality, and conserve or save ground-water supplies. This is accomplished primarily through regulating the spacing of wells within the district boundaries, by enjoining wasteful water management practices such as allowing water to flow into roadside drainage ditches, by promoting the use of tailwater recovery pits, and by public education programs about water construction methods. Ground-water pumping is currently regulated through a permit system in the Harris-Galveston Coastal Subsidence District to prevent or control land subsidence. Similarly, there are surface water conservation districts, river authorities, and water supply districts that act to store floodwaters and convert these to water supplies. The State Soil and Water Conservation Board administers local Soil and Water Conservation Districts and associated soil and water conservation programs and water quality protection planning for some rural areas. Organizations such as these are expected to have a major role in conserving water supplies in many areas of the State in the future.

Conservation Management Methods

In some areas of the State long-term water supplies can be increased through the joint use of ground- and surface-water supplies. In parts of South Texas and in West Texas, where precipitation is light and surface-water supplies are extremely limited, ground water has been developed and with continued use will ultimately be exhausted. In Gulf coast areas ground-water development and use has lowered water tables and resulted in subsidence. In both types of environments, the development and use of supplemental surface-water supplies can serve to reduce the severity of declining ground-water supplies. In the latter case, average annual recharge to aquifers can be withdrawn in future years without further subsidence, but additional supplies of water to meet growing needs should be obtained from surface-water sources. In the case of arid regions where ground water is being mined and will ultimately be exhausted, surface-water reservoirs can be used to supplement local area supplies, particularly for municipal and industrial purposes. Even though such projects may have very low quantities of dependable supplies, the average supplies are greater and can be drawn upon to meet a part or all of the water supply needed for short periods of time, leaving ground water in storage for later use. In the traditional sense of yield of reservoirs, such projects would be overdrafted in the short run in order to use the water before evaporation returned it to the atmosphere. By using such projects in this manner, exhaustible ground-water supplies would be saved for later use. Several cities in West Texas could benefit from this type of water management. Projects are being planned on the basis of this principal.

The use of treated municipal wastewater for some industrial purposes and for agriculture reduces the demand for water from original sources, and in effect, is a water conservation tool. Recharging aquifers with highly treated effluent can increase the effective supply of water is some areas. This practice is being adopted by El Paso.

In addition to water management methods mentioned above, the system operation of reservoirs within a basin, and the system operation of neighboring basins can increase the yields of such basins. Using the principals of system operation, downstream reservoirs are overdrafted to meet downstream needs. Water is retained in storage in the upstream reservoirs and released for downstream use after other downstream supplies have been depleted. In this manner, downstream reservoirs will have more vacant conservation volume in which to capture and store flows than would otherwise be possible. Likewise, if conveyance facilities are developed between neighboring basins, floodwaters can perhaps be moved into vacant conservation storage in neighboring basins and thereby increase water supply yields.

Water Supply Development

The construction of dams and reservoirs and the development and use of ground-water resources have been and continue to be the primary methods of increasing water supplies. Although water conservation is a viable method to extend water supplies, the development of additional sources will be required to ensure adequate future water supplies for the State. Each method is described briefly below.

Surface-Water Development

About 64 percent of the dependable yield of Texas reservoirs is being used to meet current needs; the remainder is committed for expanding municipal and industrial needs of the next 20 to 30 years in areas which can be served by these supplies. However, these supplies will not meet the projected future needs within their respective locations, with a few exceptions, and of course cannot meet all future needs in neighboring and more distant locations. A part of projected future needs of some basins can be met if additional reservoir sites within these basins and in nearby basins are developed. Reservoir sites have been identified, and the time of need for water supply from each site and costs of developing each site have been estimated. These estimates are shown in Part III.

Development of Texas' remaining 65 major reservoir sites will add about 4.3 million acre-feet of dependable water supply and 1.0 million acre-feet of water yield from recapturable, treated wastewater return flows. However, parts of sites suitable for reservoirs are being converted to other uses that would conflict with future water development. Some sites have significant quantities of lignite which must be mined before reservoir development can proceed. Some sites have environmental concerns which must be resolved.

Ground-Water Development

Ground water is presently providing 61 percent or 10.9 million acre-feet of water each year in the State. In 1980, the estimated total quantity of water that could be recovered from storage in both major and minor aquifers across the State was approximately 430 million acre-feet. Like surface-water supplies, ground-water resources are unevenly distributed and recharged at unequal rates. For example, the High Plains (Ogallala) Aquifer in the High Plains region contains about 89 percent of the State's ground water, but receives only eight percent of the estimated annual recharge of the State's major aquifers (Table II-1).

The continued long-term development and use of ground water is limited by the fact that more ground water is being removed in many areas of the State than is being replaced by natural recharge. In these areas, the resource is being mined, while in some other areas of the State, the ground water resources are not completely developed. It is expected, however, that ground water will continue to be an important source of water in the future.

Ground-water resources include not only the water itself, but also the storage capacity of aquifers and the capability of aquifers to transmit water from areas of recharge to points of withdrawal. Since some aquifers can be artificially recharged through the use of recharge dams and injection wells, some additional water supply development is possible. Where these conditions do not exist, the continued use and development of ground water requires programs of conservation to extend ground-water supplies. However, it is emphasized that in many areas now using ground water the reserves will ultimately be exhausted, even though more aggressive water conservation programs are carried out. In other areas ground water can continue to be an important part of the long-range supply. Specific estimates are given in Part III.

Desalting

The conversion of brackish and saline water resources to potable water can produce new sources of freshwater. Desalting is a process by which this saline and brackish water is converted to freshwater by the removal of dissolved salts, other inorganic materials and particulates, as well as viruses and bacteria. These processes include distillation, electrodialysis, and reverse osmosis. In distillation, freshwater is condensed from water vapor produced from heating saline water, while electrodialysis is an electrically accelerated process that separates salts from saline water through a membrane. In reverse osmosis, freshwater is produced from a saline solution by pumping the solution through a membrane filter under pressure.

Recent research and development have reduced the costs of converting saline water to freshwater so that such conversion is currently being used commercially for municipal and industrial supplies at approximately 650 locations in the United States and 1,600 locations in other countries. Today, there are 71 desalting plants in Texas producing about 52 acre-feet of water per day for municipal and industrial purposes. Of these, the majority is for industrial purposes followed by those producing boiler feedwater for electric power generation. Seven plants produce about 2.5 acre-feet of water per day for municipal use in Dell City and several suburban areas.

In some parts of Texas desalting may prove to be the most economical and feasible means to supplement municipal water supplies or to comply with federal drinking water standards. This could include the use of brackish and saline ground and surface water as well as seawater and is applicable in much of the Panhandle, West and Western

Central Texas, the Lower Rio Grande Valley, and along the coast. Nevertheless, some constraints do exist to its widespread use. Because desalting is an energy-intensive process, the costs of energy may be a limitation. Furthermore, one of the important considerations of a desalting system is the disposal of waste brine, since this increases the costs of the project.

Weather Modification

Efforts to artificially induce or modify precipitation with the use of silver iodide, frozen carbon dioxide, and other means may be a potential way to increase water supplies in the future. Although weather modification includes techniques to increase rain or snow, suppress hail, dissipate fog, and to mollify severe storms, in Texas, weather modification has involved the seeding of clouds to increase rainfall. While a number of independent research projects indicate that rainfall can be increased as much as 10 to 50 percent in the western United States, in the target area of a cloud-seeding project conducted in West Texas during the 1970's, approximately 28 percent more rain was reported than was observed in neighboring areas in the same years. Although promising, these techniques are not yet proven, and additional research is required in order to appropriately consider weather modification as a viable method to increase water supplies. If weather modification is developed into a viable water supply tool, it will be necessary to also develop legal and institutional arrangements for its administration.

Importation

Water supplies of several areas of the State are insufficient to meet projected long-term needs. Rapid metropolitan growth in Houston has resulted in the development of surface water to supplement and replace ground-water use. Agriculture and municipalities in the Winter Garden area are competing with San Antonio for water from the Edwards Aquifer. In addition, areas in East Texas will require more water to meet population growth and to support the production of lignite, while ground-water mining for municipalities and agriculture in the High Plains is depleting the Ogallala Aquifer. El Paso and other areas within the Rio Grande Basin will also need water from other sources. To meet the expanding water needs of the State, it is important to consider all alternatives to supplement these diminishing supplies, including the importation of surplus water from outside the State. Efforts are being continued to locate excess supplies, to evaluate the feasibility and costs of transporting water into the State, and to provide arrangements that are mutually beneficial to Texas and the areas from which water might be imported.

PROJECTING FUTURE WATER DEMANDS

In this section, each major water-using purpose is identified, defined, and explained, and a brief explanation is given of the methods, procedures, data, and assumptions used in making projections of future water demands for each purpose. The major water-using purposes are: municipal and commercial, industrial, steam-electric power, agriculture, mining, hydroelectric power, navigation, bays and estuaries, instream flows, parks and fish hatcheries, and public recreation. Projections of future demands for each purpose are presented in Part III for each zone of each river basin within the State, for each decade from 1980 to 2030. Projections are made for two different rates of growth, referred to in the discussion as "low" and "high."

Municipal and Commercial Water Demand

With the exception of some light manufacturing operations, the municipal and commercial water use category contains the quantity of water used by business establishments, public offices and institutions (except municipally-owned steam-electric generating plants), private residences and the maintenance of their grounds, fire protection, and other users supplied from municipal systems. Light manufacturing water use is counted in the municipal category, in distinction to the industrial use category, since the characteristics of water use—drinking, sanitation, air-conditioning—in these manufacturing firms more closely compare to the characteristics of municipal use than to the characteristics of industrial use. Of the 17.9 million acre-feet of water used in Texas in 1980, municipal and commercial use accounted for 15.6 percent or 2.8 million acre-feet.

Future municipal and commercial requirements are based upon population projections and per capita water use data. Projections of population were made for each Texas county by decade to the year 2030. Within the constraint of the overall county projections, the future population of cities and towns located within counties was also projected, along with that portion of each county's population residing in rural areas. The county, city, and rural-area projections were grouped into their respective zones and river basins in order to be able to project water demands for each of these water resource areas. State projections of population are the sum of the 254 individual county projections.

Two sets of population projections were made: one, the high case, uses vital statistics from each Texas county and net migration data of the 1970's, and a low case is based on the same vital statistics data but with net migration characteristics that reflect migration patterns of the

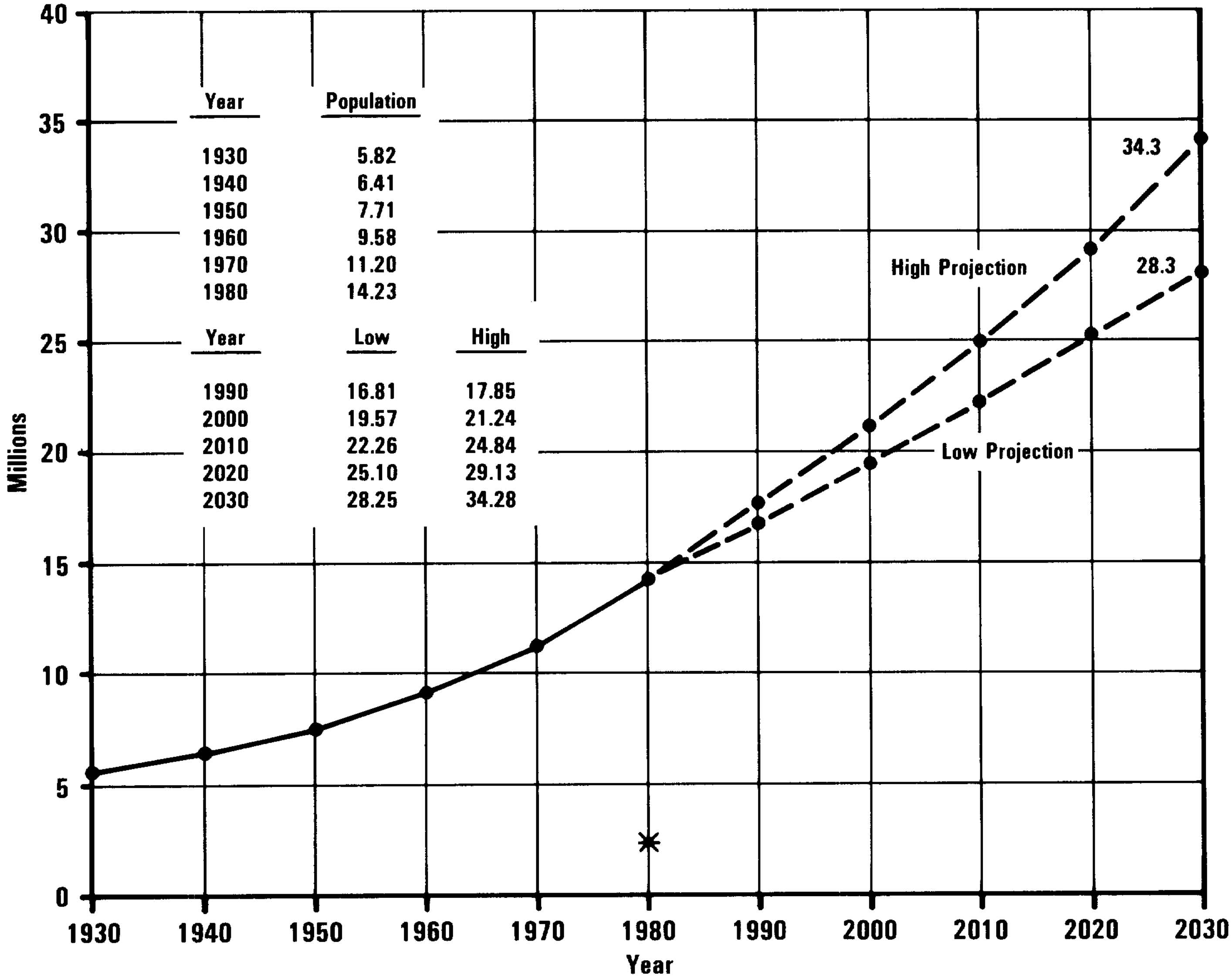


Figure II-6. Texas Population, With High and Low Projections to 2030

past three decades (1950-1980), which has the effect of reducing the influence of the very high rate of immigration into Texas in the latter portion of the decade of the 1970's.

In the high set of projections, the State population total is over 21 million by 2000, increasing to 29.1 million by 2020, and to over 34 million by 2030 (Figure II-6 and Table II-2). The slowing of the growth rate after 1990 reflects anticipated changes in fertility, migration, and economic variables which affect population changes. Texas growth is projected to continue to outpace almost all other states, however, with a doubling of present population by about the year 2020.

The low set of projections has a slower rate of growth over its entire range with the State population increasing from 14.2 million in 1980 to 28.3 million in 2030. Under the conditions of this set of projections, the population of Texas in the year 2000 is estimated at 19.6 million persons.

Per capita use of water is projected for each city and each county, based on water use data reported by the municipal and commercial suppliers within each county. Thus, the climatological, economic, and other factors affecting water use for municipal purposes in the different areas of the State are taken into account within the respective water use reports.

Although per capita water use for individual cities differs from the State average of all cities, the long-term average daily per capita water use in Texas cities has been

Table II-2. Texas Population with Low and High Projections to 2030.

Year	Low Case Population (millions)	Low Case Rate of Growth (percent)*	High Case Population (millions)	High Case Rate of Growth (percent)*
1930	5.8	—	5.8	—
1940	6.4	10.3	6.4	10.3
1950	7.7	20.3	7.7	20.3
1960	9.6	24.7	9.6	24.7
1970	11.2	16.7	11.2	16.7
1980	14.2	26.8	14.2	26.8
1990	16.8	18.3	17.8	25.4
2000	19.6	16.7	21.2	19.1
2010	22.3	13.8	24.8	17.0
2020	25.1	12.6	29.1	17.3
2030	28.3	12.7	34.3	17.9

SOURCE: U.S. Bureau of the Census with projections by the Texas Department of Water Resources. * Rate is per 10 years.

increasing at about four gallons per person per decade since the early 1960's. In 1960, per capita water use in Texas was reported at 128 gallons per day. In 1974, per capita water use was 144 gallons per day, and in 1980 was 176 gallons per day. Average per capita water use is projected to be 156 gallons per day in 1990 and 160, per day in 2000.[1]

For planning purposes, municipal system water requirements were projected for two cases of future population and two different per capita use rates—low and high population projections and average and drought condition per capita water use rates, with the estimated potential effects of water conservation factored into each case. Projections were made for individual cities and for rural areas of each county (Appendix A).

The differences between the low and high population projections for each city are due to projected differences in net immigration to each city. The low projection is based on average net immigration rates for the decades of the 1950's, 1960's, and 1970's. The high population projection is obtained by using the same immigration data, but without dampening or reducing the high rates of the late 1970's, as is done when making the low projections.

[1]Actual per capita municipal water use in 1980 is higher than projected average per capita use in 1990 and 2000 due to extremely hot, dry weather conditions throughout most of Texas during the summer of 1980. Measured against the long-term trend, actual useage in 1980 was about 20 percent higher. In contrast, 1960 was an exceptionally cool, wet year.

The differences between the average and drought condition per capita water use rates are due to expected differences in water use between normal and drought seasons. The per capita water use in a city during years of normal precipitation is best estimated by the average per capita water use computed from water use reports for such years. However, during drought years per capita water use increases because temperatures are higher, causing a higher water demand by all water-using functions, and during droughts the lack of precipitation causes water users to have to obtain more water from storage than would otherwise be necessary. Thus, municipal water systems must be prepared to meet average condition demands at all times, and must also be prepared to either meet drought condition demands or to ration water during drought periods. Managers of each system are free to decide whether or not to try to meet drought condition demands. Obviously, a larger quantity of water will be needed than is needed for average weather and climate conditions. Information from Texas municipal water systems indicates that during drought years per capita water use is greater than during average years by a quantity which is approximated by two standard deviations above average per capita use. Thus, for planning purposes the drought condition per capita water use statistic is chosen to be the average per capita water use plus the estimate of two standard deviations of State municipal water use.

The high set of projected municipal water requirements is obtained by using the high set of population projections and drought condition per capita water requirements, with per capita use held constant in 2010, 2020, and 2030 at the per capita drought rate projected for 2000. This projected flattening of the per capita rate after the year 2000 would be a result of water conservation. The low set of projected water requirements is based on the low population projections and average climatic conditions, with per capita use held constant in 2010, 2020, and 2030 at the per capita rate for average conditions in 2000.

The potential effects of conservation practices on municipal and commercial water use, mentioned above and discussed in more detail in Part IV, play an important role in determining the future per capita water use rates applied in estimating future municipal and commercial water requirements. For the high set of projections, based on per capita usage under drought conditions, the adoption of water conserving practices and installation of water saving devices directly enter into the computation of estimated future requirements in that per capita water use in the years 2010, 2020, and 2030 are held constant at the use rate projected for 2000. That is, the long-term temporal increase in per capita water use rates statistically observed in Texas is projected to stop growing after the year 2000. The period of time between the present and the year 2000 is anticipated to be needed for homeowners and commercial managers to adopt practices and install equipment designed to reduce water use and for public authorities to adopt changes and enact codes directed toward water pricing, plumbing, fixtures, allowances for graywater usage, and for public education programs. The use of drought condition per capita water use rates in preparing the High Case projections is designed to provide planning data useful in making engineering determinations of the necessary size of water supply projects and water treatment and distribution facilities. Decisions regarding facility sizing are made by local authorities in response to local conditions and the needs and preferences of their water customers.

The Low Case projections, based on average condition per capita water use rates, with no future increase in average use rates anticipated beyond the year 2000, continues the effects of conservation practices factored into the High Case projections. However, systems engineered and built to meet only average condition demands will be strained beyond their limits in the event of a drought or a hot, dry summer and would not be expected to meet all the demands placed upon it. Thus, in addition to implemented conservation practices, drought contingency plans designed to reduce water use in the event of drought or excessive demand on a water supply or treatment and delivery system will have to be put in effect. Such plans, discussed in detail in Part IV, must have the effect of restricting and rationing water use.

The projections of municipal and commercial water requirements for the low case increase from the 1980 statewide level of 2.8 million acre-feet to a total of 3.5 million acre-feet per year in 2000 and to 5.1 million acre-feet annually by 2030 (Table II-3 and Figure II-7). For the high case, water requirements for municipal and commercial purposes are projected to increase to 5.1 million acre-feet annually in 2000 and to 8.2 million acre-feet annually in 2030. Projections of municipal and commercial water requirements by decade for each zone and river basin area of the State are presented in Part III.

Industrial Water Demand

Since the 1940's, the Texas economy has expanded and the economic base has been broadened from petroleum and agriculture to petroleum, agriculture, electronics, machinery and equipment, construction, trades, communications, and many types of professional and business services. During the 1970's, chemicals, petroleum refining, metals, and oil field machinery experienced rapid growth in production, employment, value of output, and wages paid. These and other industries used 1.5 million acre-feet or 8.5 percent of total water used in Texas in 1980. For planning purposes it is necessary to make projections of the quantities of water that will be needed by industry in future years.

While the basic industries remain a solidly significant portion of the Texas industrial base, it is not anticipated that all of them can maintain the high rates of growth of the recent past. Primarily, the abundantly available and low-cost input resources that gave Texas a comparative advan-

Table II-3. Municipal and Commercial Water Use in 1980 with Low and High Projections of Requirements to 2030.

Year	Projected Water Requirements	
	Low Case	High Case
	(millions of acre-feet)	
1980[1]	2.81	2.81
1990	2.96	4.20
2000	3.51	5.08
2010	3.99	5.93
2020	4.50	6.95
2030	5.06	8.18

[1]Reported municipal and commercial use. The summer of 1980 was extremely hot and precipitation was low for about four months. Reported water use for 1980 was greater than average, but was below the estimated quantity that would have been used if a drought had prevailed for the entire year.

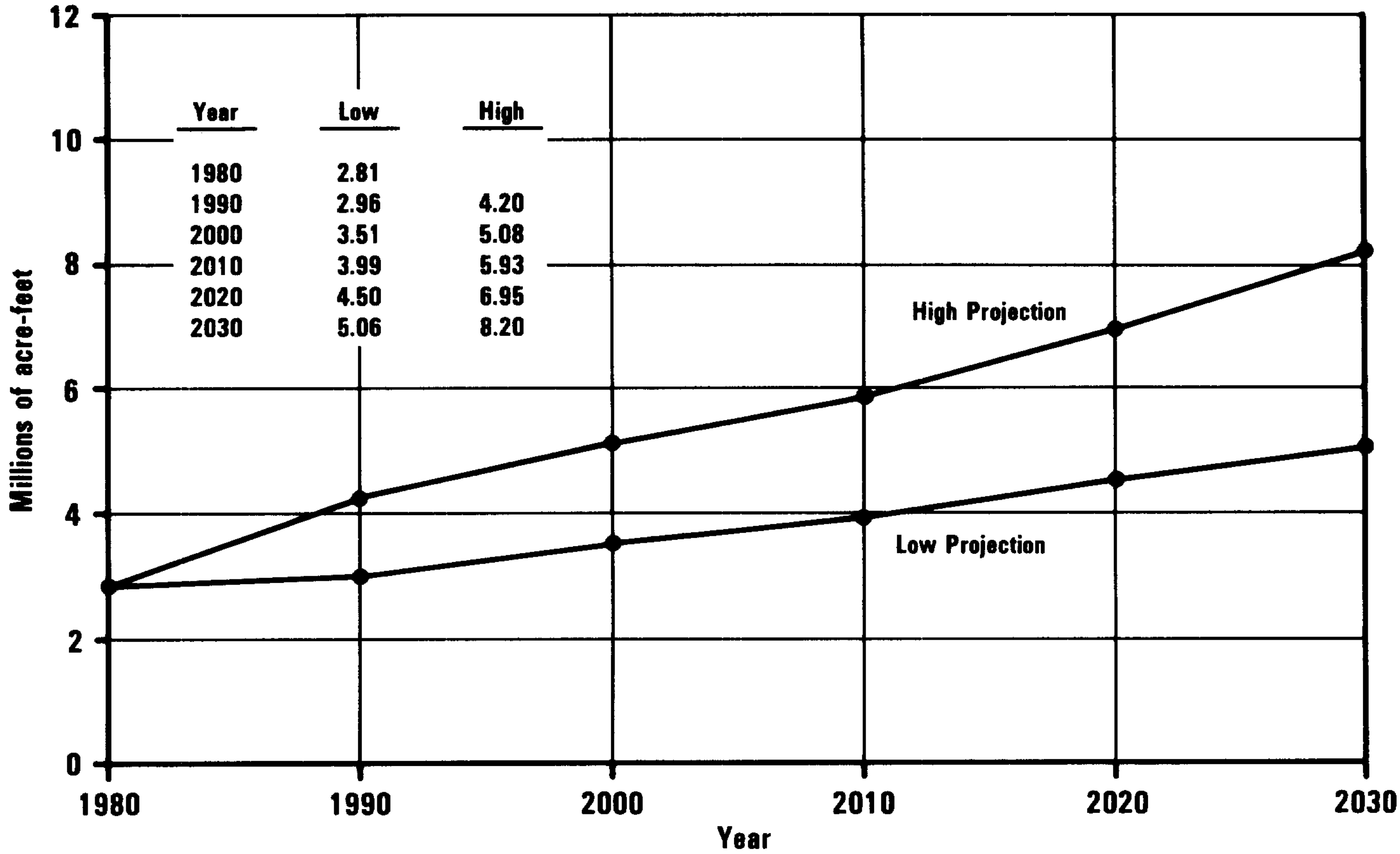


Figure II-7. Projected Municipal and Commercial Water Requirements, High and Low Series, 1980 to 2030

tage in attracting and developing these industries are either becoming scarce in Texas or are becoming relatively less costly elsewhere, especially outside the United States. For example, the production of aluminum and bulk plastics initially were attracted to Texas by the availability of inexpensive electricity, oil, and natural gas. None is as inexpensive in Texas today as has been the condition in the past. Similarly, the production of ferrous metals and oil field materials and machinery are mature industries and their future will to an extent parallel drilling and production of Texas' crude oil and natural gas. Thus, slower growth is expected for these industries than has occurred in the past. Other factors, especially world market conditions, now impact Texas industry more directly and intensely than in the past. National economic conditions and rates of growth are steadily becoming more important determinants of industrial growth because the structure of Texas industry is beginning to resemble that of the Nation, as diversification increases within Texas. All of these factors impinge upon water requirements for industry in the future.

Water used for industrial purposes is distinguished from water used for municipal and commercial purposes in that it is an integral part of the production process. In addition to drinking and sanitary water uses, industrial water requirements serve such process-specific purposes as cooling, boiler feed, cleaning and washing, pollution control, and extraction and separation of desirable materials from by-products and waste materials. Incorporation of water into the final product also is a major aspect of industrial water demand, especially in the production of food and beverage products.

Of the total quantity of water used by industry, five major groups of industries accounted for over 90 percent of total usage in 1980. Organized into industrial groups by the Standard Industrial Classification (SIC) System and ordered by their respective share of industrial water use, the five major industrial water using industries are: (1) chemicals (SIC 28), 36.6 percent; (2) petroleum refining (SIC 29), 19.4 percent; (3) primary metals (SIC 33), 15.0 percent; (4) paper products (SIC 26), 12.7 percent; and effectiveness, of the maximum reduction in water needed for production in the five largest water-using industries operating in Texas. Adoption of these feasible water conserving techniques was stretched out over a future period of time to allow for an adoption path consistent with an installation lag-time and for ordinary practices of replacement of worn out equipment with new, more efficient equipment. The low set of manufacturing requirements projections has factored into them the full measure of feasible reductions in water required per unit of output; the high set was adjusted, to reflect the effect of conservation, by one-half this measure of practicable possible gain in water use efficiency.

From a 1980 statewide total of 1.5 million acre-feet, industrial water demands in the low case are projected to increase to 2.4 million acre-feet annually by 2000 and 4.2 million acre-feet annually by 2030. The potential high demand projections are 2.7 million acre-feet annually and 5.0 million acre-feet annually for 2000 and 2030, respectively (Table II-4 and Figure II-8). These projections indicate an anticipated increase in industrial water requirements in Texas for the year 2000 of between 58.6 percent and 78.9 percent, comparing 1980 actual use with the amounts projected for requirements in 2000, low and high case, respectively. By the year 2030 this same comparison to base-year usage indicates increases of 178.3 percent and 229.6 percent, respectively, a near tripling of requirements for the low case and more than tripling for the high case. Part III contains projections of future industrial water demand by decade for each zone and river basin of the State.

Steam-Electric Power Water Demand

Steam-electric power plants require large volumes of water, principally for condenser cooling. Water in small quantities is also required for boiler feed makeup, sanitation and grounds maintenance, and in the case of coal and lignite fueled plants, for flue gas scrubbing (air pollution control), dust control at the fuel handling facilities, and for ash removal. In instances where a mine is associated with the plant, as is common at Texas lignite-fired plants, water will also be required for the mining operations. Consumptive (evaporative) water requirements for power plant cooling typically range from one-third to one-half gallon of water for each kilowatt-hour of electricity produced. The actual quantity depends on the specific type and design of the power plant and most importantly on the type of cooling system used. Consumptive water requirements for all other minor purposes will add about 10 percent to the per kilowatt-hour consumptive requirements for cooling.

Table II-4. Industrial Water Use in 1980 with Low and High Projections of Requirements to 2030.

Year	Projected Water Requirements: Low Case (millions of acre-feet)	Projected Water Requirements: High Case (millions of acre-feet)
1980[1]	1.52	1.52
1990	1.97	2.12
2000	2.41	2.72
2010	2.86	3.31
2020	3.47	4.08
2030	4.23	5.01

[1]Reported and estimated industrial water use in 1980. Projections to 1990 and beyond were based upon plant utilization data which were corrected for underutilization in 1980 due to the economic recession that began in mid-1980.

The most commonly used cooling systems are recirculating cooling reservoirs, evaporative cooling towers, once-through cooling systems, and multipurpose reservoirs used as cooling reservoirs. In all of these systems, from 20 to 60 gallons of water are circulated through the power plant condenser for each kilowatt-hour of electricity produced. The water is then cooled and recirculated, as in the case of evaporative cooling towers and recirculating cooling reservoirs, or it is discharged into a lake where only a small portion of the same water is recirculated through the plant.

Water requirements for steam-electric power generation were based on projections of electric power demand, the energy source used for generation, and the spatial location of generating capacity. The water coefficients used were based on engineering analyses of the thermodynamics of power plant operations, including an analysis of secondary water uses. For plants in the design phase of development, specific engineering design coefficients pertaining to water requirements were used, whenever available, in estimating future water requirements. For generating capacity scheduled for placement for which design work had begun, future water requirements were based upon the types of fuel anticipated for use in the basin and zone of plant location and upon an advanced plant engineering design appropriate for each fuel type. The projections of electric power demand to the year 2000 are based on projections made by the power industry, and projections beyond 2000 are based on data developed by the Department of Water Resources. Population projections were used to estimate electric power demand in residential, commercial, and institutional sectors, and manufacturing projections were used to estimate power demand in the industrial sectors.

Two cases, low and high, of power demand were made based on different rates of growth (Table II-5 and Figure II-9). The projections of future installed net thermoelectric generating capacity indicate that the net capacity in

(5) food products (SIC 20), 7.2 percent. Since future water use in the industrial use category is expected to be dominated by these five industrial groups, future projections of water requirements will depend on the level of production and rate of growth of these industries in the future. Based upon data, advice, and judgments by representatives of these industries, a growth outlook for each industry was developed for use in making projections of future water requirements. The growth projections are as follows:

Chemicals (bulk)—Major changes in markets and worldwide competition from new petrochemical complexes pose a long-term threat to Texas' position in the industry. Texas producers expect to maintain rapid growth in output for the short term, ten to twenty years; however, significant long-term expansion of capacity is unlikely. The compound annual growth rate projected for chemicals during the decade of the 1980's is 4.94 percent per year, which includes an allowance for reutilization of excess productive capacity that existed in 1980. For the decade of the 1990's the projected compound annual growth rate is 3.79 percent per year; for the period 2000-2030 the projected growth rate is 2.79 percent per year.

Petroleum Refining—Demand for products is heavily impacted by improved energy use efficiency in transportation and by substitute energy sources in the long term. Little growth is projected for this sector. Petroleum Refining output is projected to grow at a compound annual growth rate of 1.26 percent per year during the 1980's and at 0.42 percent per year during the 1990's, where each growth rate reflects exclusively the utilization of excess capacity existing in 1980—no new facilities will be installed. No growth is projected during the period 2000 to 2030.

Primary Metals—Annual growth rate of output from Texas producers is influenced by: (1) foreign competition, (2)eventual decline in demand from oil and gas exploration markets, (3) the use of recycled aluminum which requires relatively little water per unit of output, and (4) prohibitive process-energy costs which render primary metals' production uneconomical in the State. Modest growth is projected for Primary Metals during the decade of the 1980's, 3.0 percent per year, including recovery of excess plant capacity, slowing to 0.5 percent per year compound annual growth during the 1990's. No growth is projected for this sector beyond the year 2000.

Pulp and Paper—Available Texas timber resources will constrain the long-term growth rate of the industry, although growth in market demand for paper products is expected to remain strong. The eventual substitution of other methods of communication such as electronics and alternative methods of packaging may result in a dampening effect on industry growth. This sector is projected to grow at a compound annual rate of 4.01 percent per year during the 1980's, including reutilization of existing excess capacity, and at 2.0 percent annually during the 1990's. In the period 2000 to 2030, compound annual growth is projected to be 0.9 percent per year.

Food Processing—Texas industry is anticipated to grow faster than the national average for food products. Over the long-term, output will be slowed somewhat as population growth rates slow, yet steady growth is likely. The Food Processing sector is projected to have reasonably steady compound annual growth of 2.38 percent per year during the 1980's, 2.64 percent per year during the 1990's, and 2.15 percent per year for the period 2000-2030.

As with the projections of future municipal water requirements, a low and a high set of future industrial water requirements projections was made. The principal characteristics that distinguish between the low and high set of projections are the different rates of overall industry growth in Texas and the rate of implementation of industrial water conservation techniques.

Two rates of growth in output were projected for Texas industries and, thus, projections were obtained of two different volumes of industrial water requirements to support the respective levels of industrial output. The two growth rates, a low and a high, reflect different underlying growth patterns in national and international economic activity as well as a smaller or larger share of national and international markets held by Texas producers. Also factored into the low and high series of industrial water requirements projections were two different rates of gain in industrial water-use conservation: a modest rate of gain was applied to the high set of requirements projections, a more accelerated rate of gain into the low set.

Considerable gains have been made in recent years in reducing the amount of water used per unit of final output manufactured. By changing machinery and equipment, production processes, or mix of inputs, efficiencies in water use can be achieved. Current developments, the state of existing available technologies and management practices, and continuing attention to potential production cost savings from using less water in production of manufactured goods point to the potential for further reducing water intake required per unit of industrial output, especially in those industries in Texas that are heavy users of water. Estimates were made, within the constraints of existing state-of-the-art technologies and cost

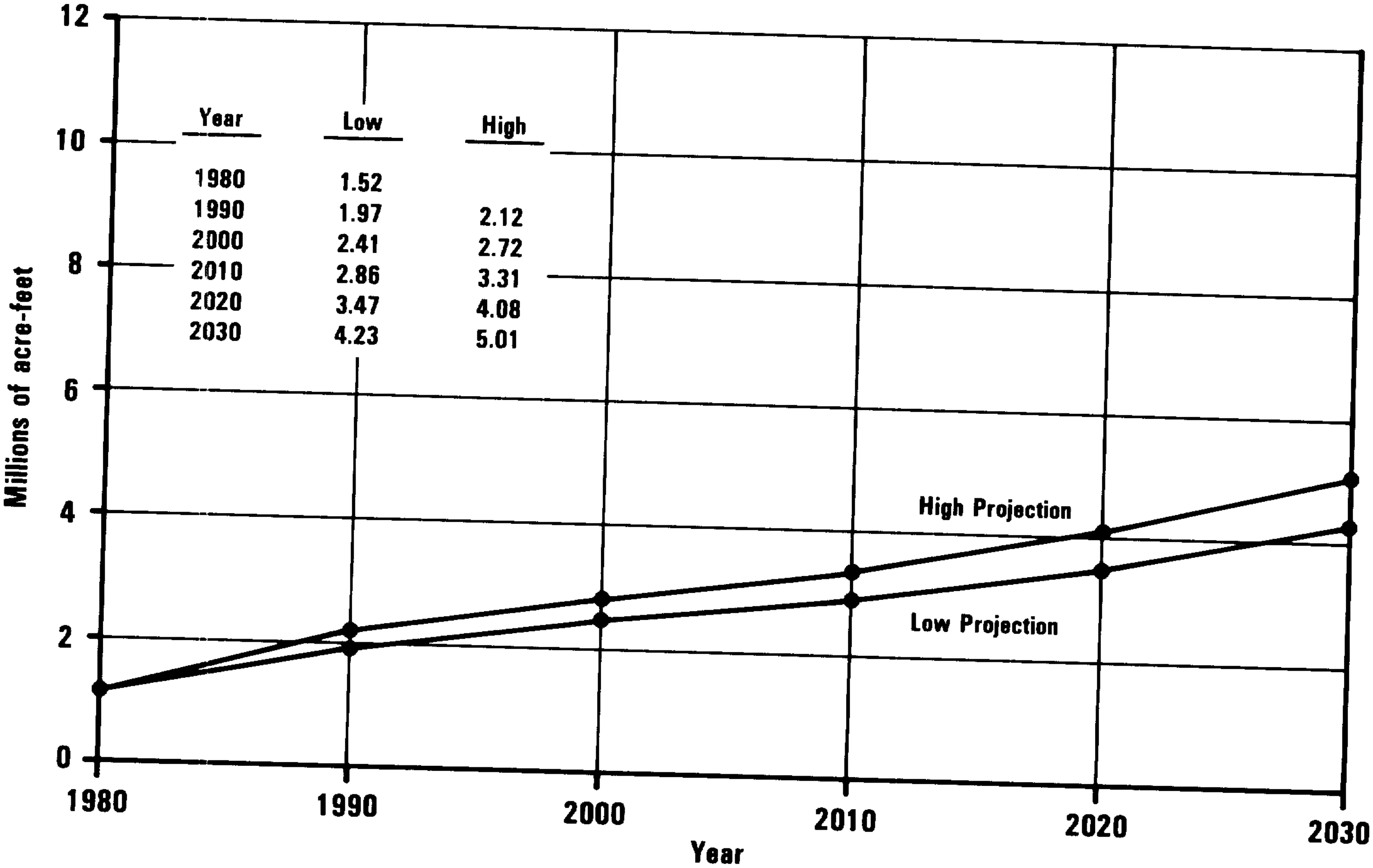


Figure II-8. Projected Industrial Water Requirements, High and Low Series, 1980 to 2030

Texas will grow from 50.7 thousand megawatts in 1980 to between 88 thousand and 100 thousand megawatts in the year 2000, then increase to between 120 and 152 thousand megawatts by the year 2030, low and high case, respectively.

Table II-5. Steam-Electric Water Use in 1980 with Low and High Projections of Requirements to 2030.

Year	Projected Water Requirements	
	Low Case	High Case
	(millions of acre-feet)	
1980[1]	330.0	330.0
1990	535.0	535.0
2000	717.4	816.7
2010	835.4	1,017.0
2020	975.6	1,217.0
2030	1,118.6	1,417.5

[1]Reported and estimated steam-electric water requirements for 1980.

At present, natural gas is still used as the primary fuel for about 65 percent of the electricity generated in Texas, but coal, lignite, and uranium will be the major fuels in the future. In 1980, Texas had 5,300 megawatts of lignite-fired generating capacity and 6,431 megawatts of coal-fired generating capacity. By 1990, an additional 8,759 megawatts of new lignite capacity, 3,324 megawatts of new coal-fired capacity, and 4,800 megawatts of nuclear capacity will be added to the system, according to the utility industry plans. Between 1990 and the year 2000, lignite is projected to fuel two-thirds of the new plants, while coal will fuel the remainder. This will place total projected lignite-fueled generating capacity in Texas at between 24 and 33 thousand megawatts in the year 2000. Beyond the year 2000, lignite is projected to continue to play a significant role, but lignite-fueled capacity is projected to peak at 65 thousand to 75 thousand megawatts around the year 2015. Then, because of limited lignite resources, lignite generating capacity is projected to decline to around 40 thousand megawatts by the year 2030. Coal is projected to account for most of the remaining capacity.

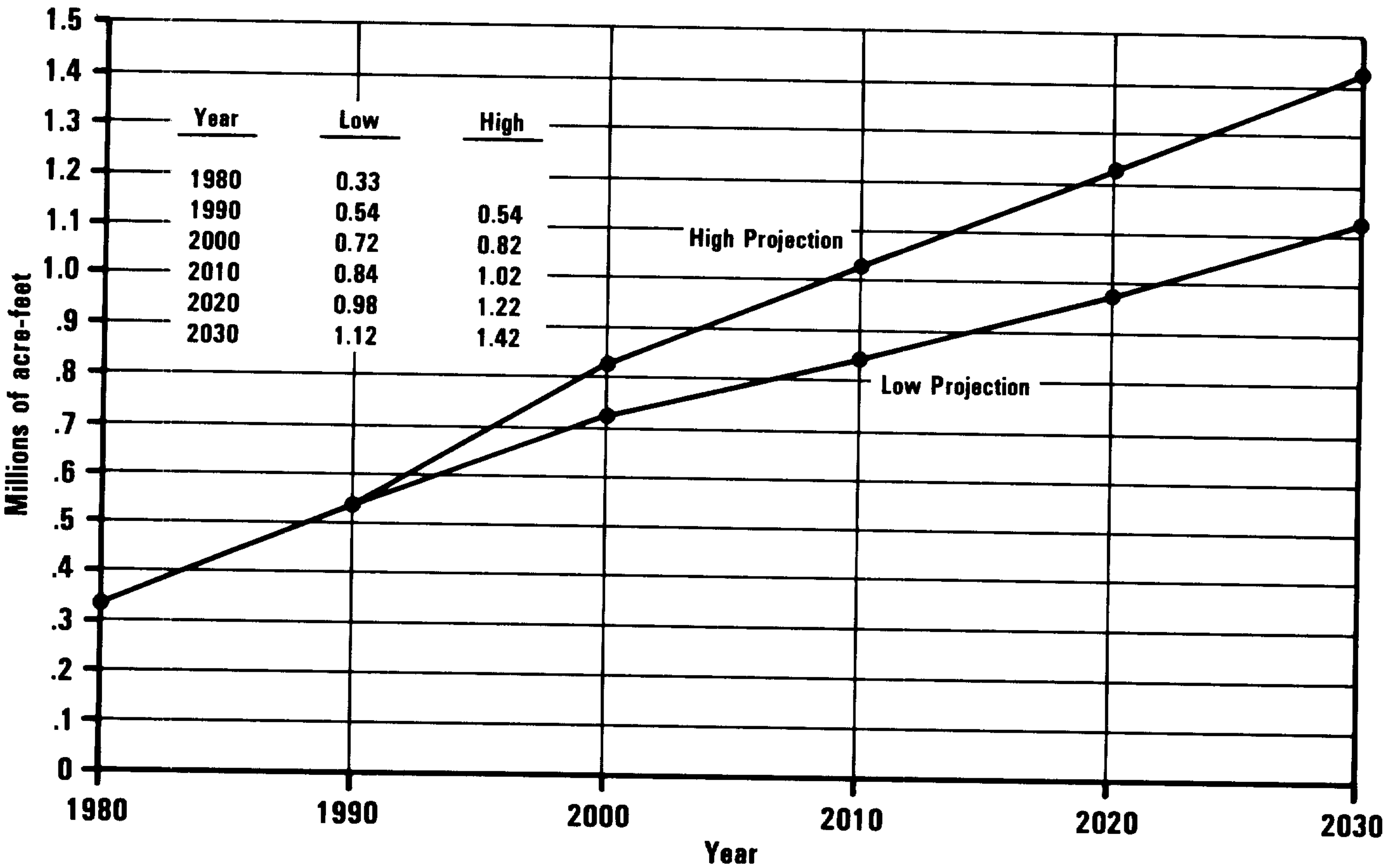


Figure II-9. Projected Steam-Electric Water Requirements, High and Low Series, 1980-2030

The distribution of generating capacity was based on announced power plant locations, historical development by basin, projected demand for power, availability of local fuel sources such as lignite, environmental factors, and institutional constraints.

Total (cooling and other needs) consumptive water requirements (evaporation) for steam-electric power production were projected to increase from 330 thousand acre-feet in 1980 to between 717 and 817 thousand acre-feet annually in 2000, and to between 1.1 and 1.4 million acre-feet per year in the year 2030, low and high case, respectively. Although large volumes of water must be circulated through power plant condensers (20-60 gal/kw-hr), most of the water is returned to its source. Only the quantity of water that is evaporated is shown when projecting steam-electric power plant water requirements. However, for operating purposes, it is necessary that the total quantity of water required for circulation be available. The projections of Part III take this latter factor into account.

Surface water is projected to continue to constitute the major portion of steam-electric power water use, increasing from 277 thousand acre-feet per year in 1980 to between 580 and 641 thousand acre-feet per year in the year 2000, and to between 900 thousand and 1.14 million acre-feet per year by 2030. Ground-water use is projected to triple from current levels of 53 thousand acre-feet per year to between 140 thousand and 176 thousand acre-feet annually by the year 2000, and then nearly double again by the year 2030 to between 150 thousand and 274 thousand acre-feet per year. Treated municipal effluent is currently used at four major power plants in Texas for cooling water and other purposes. In 1980, these four plants used over 14 thousand acre-feet of treated effluent.

As indicated, the future water requirements specified above account only for the volumes of water consumed (evaporated) in the respective decades in steam-electric power generation. Since nearly all the water used in power generation is for cooling purposes and only a small portion of this is evaporated, the pass-through requirements are a large multiple of that volume of water evaporated. Pass-through requirements for power plants operating in Texas range from 20 to 60 gallons per kilowatt-hour. A typical value for plants using fresh surface water cooling systems, such as cooling ponds or once-through cooling, is around 40-50 gal/kw-hr. This translates to about 100 gallons of total water pass-through requirements for each gallon of water actually consumed by surface water cooled power plants.

Based on the future projections for evaporative requirements in steam-electric power generation, the range of low and high projections for total pass-through requirements in the year 2000 is from 50 million to 65 million acre-feet. For the year 2030, the projected range of requirements is from 80 million to 115 million acre-feet. This estimate of total pass-through requirements is made only upon water supplied from a surface-water source, since water supplied from a ground-water source is based on total withdrawals and, thus, includes both evaporation and recirculated flow. Total pass-through requirements measure the volume of water required to satisfy the operational needs of steam-electric power generation (cooling and other minor water requirements) but overstate by several magnitudes the amount of water consumed from available supplies, since most of the total withdrawal is returned to its source and again becomes a part of available supply. Thus, the actual water required throughout the life of a plant operating from surface water is that amount initially needed to fill the cooling pond and generate the system plus those amounts needed to make up for evaporation losses. Projections of consumptive water requirements for steam-electric power generation for each area of the State are presented, by decade, in Part III.

Agricultural Water Demand

Texas ranks first in the Nation in the production of cotton and cottonseed, grain sorghum, wool and mohair, and in the total numbers of cattle, sheep, and goats. Texas is also a leading producer of hay, pecans, peanuts, citrus, commercial vegetables, rice, and wheat. Over 40 percent of Texas crop sales is directly attributable to irrigation. Of all major water use categories, agriculture accounts for the largest proportion of water used in Texas.

In 1980, agricultural water use was approximately 12.9 million acre-feet, 72 percent of the 17.9 million acre-feet total water use in the State. Of this total, irrigation of crops, orchards, and pasture accounted for 12.7 million acre-feet to irrigate 8.1 million acres, and livestock use on farms, ranches, and in feedlots was about 0.24 million acre-feet. Irrigation in Texas was about 6.7 million acres in 1958 and increased until reaching a peak in 1974, when 8.6 million acres was irrigated. The acreage irrigated in 1980 was about six percent less than in 1974.

Approximately 38 million acres of land in the State is physically suited to irrigation, including the 8.1 million acres presently irrigated. Some land included in this estimate is located such that irrigation development might not be feasible, depending upon costs of supplying water. Urban development continues to expand onto irrigable land, especially in the Houston-Galveston, El Paso, San Antonio, and Lubbock areas, in the suburbs of smaller cities, and in the Lower Rio Grande Valley.

The quantity of land previously irrigated and still equipped for irrigation, but not irrigated in 1980 due to poor profit prospects, is approximately 2.0 million acres. Much of the previously irrigated land is in the rice-producing area of the Coastal Prairie, Reeves and Pecos Counties, and a few counties in the High Plains. Most of this acreage would be readily available for irrigation in the future if economic conditions improve.

In estimating the future water needs of irrigated agriculture, the following factors were considered: the total acreage suitable for irrigation, acreage currently in irrigated production, the 1980 water use per acre, the maximum potential reduction of water use through technological improvements and conservation practices, the economics of dryland versus irrigated production, and the Nation and world's potential food demands. One projection of water demand for irrigated agriculture, low case, was derived by holding projected future acreages irrigated at the 1980 levels, with per acre application rates reduced through time to reflect the effects of technological improvements, conservation measures, and reductions in canal losses for irrigation operations served from surface-water sources. The future agricultural water demand required to continue irrigation of the same number of acres irrigated in 1980, 8.1 million acres, making allowance for reduction in application rates, is 10.1 million acre-feet in year 2000 and 11.1 million acre-feet in 2030. These low-case projected requirements reflect a reduction from the 12.7 million acre-feet used in 1980 of 20 and 13 percent, respectively, in 2000 and 2030 (Table II-6 and Figure II-10).

For the high case projection of demand for irrigation water, data about the number of acres that could be irrigated and still pay a positive return above that of dryland production were controlling factors. In addition, technological improvements and conservation measures were considered in developing the rate of water applied per acre, as well as factoring in reductions in canal loss rates for surface water supplied irrigation. The projected demand at this higher level is 16.2 million acre-feet per year for 13.9 million acres irrigated in 2000, and 15.0 million acre-feet

Table II-6. Irrigation Water Use in 1980 with Low and High Projections of Requirements to 2030.

Year	Projected Water Requirements[1]	
	Low Case	High Case
	(millions of acre-feet)	
1980[2]	12.7	12.7
1990	10.2	12.3
2000	10.1	16.2
2010	10.6	16.2
2020	10.7	16.5
2030	11.1	15.0

[1]Irrigation water requirements for all years include an estimate for water lost in conveyance from a surface-water source to the field.
[2]Reported and estimated irrigation water use in 1980.

annually with 11.5 million acres irrigated in 2030. The high case projections of future irrigation water demand represent an increase over 1980 usage of 28 and 18 percent, respectively, for years 2000 and 2030. The corresponding percentage increases in acreage in irrigation in the two future time periods are 72 and 42 percent, respectively. Whereas the low case projections were based on constant 1980 irrigated acreages coupled with improved water use efficiencies and conservation, the high case projections were based on an analysis of profitability of irrigation, taking into account projected future agricultural prices and production costs coupled with the same improvements in water use efficiency and conservation. Specific low and high projections are shown for each zone and river basin area in Part III.

Livestock water use in 1980 was 244 thousand acre-feet, supplied both from local surface- and ground-water sources (Table II-7). Projections of livestock water demands are based on maintaining Texas' share of National livestock production until limited by availability of land for grazing. Feedlot cattle, hogs, dairy, and poultry sectors are not limited by this acreage requirement. Livestock water demands for the period 2000-2030 are approximately 332 thousand acre-feet annually. Distribution of these demands into county, basin, and zone seg-

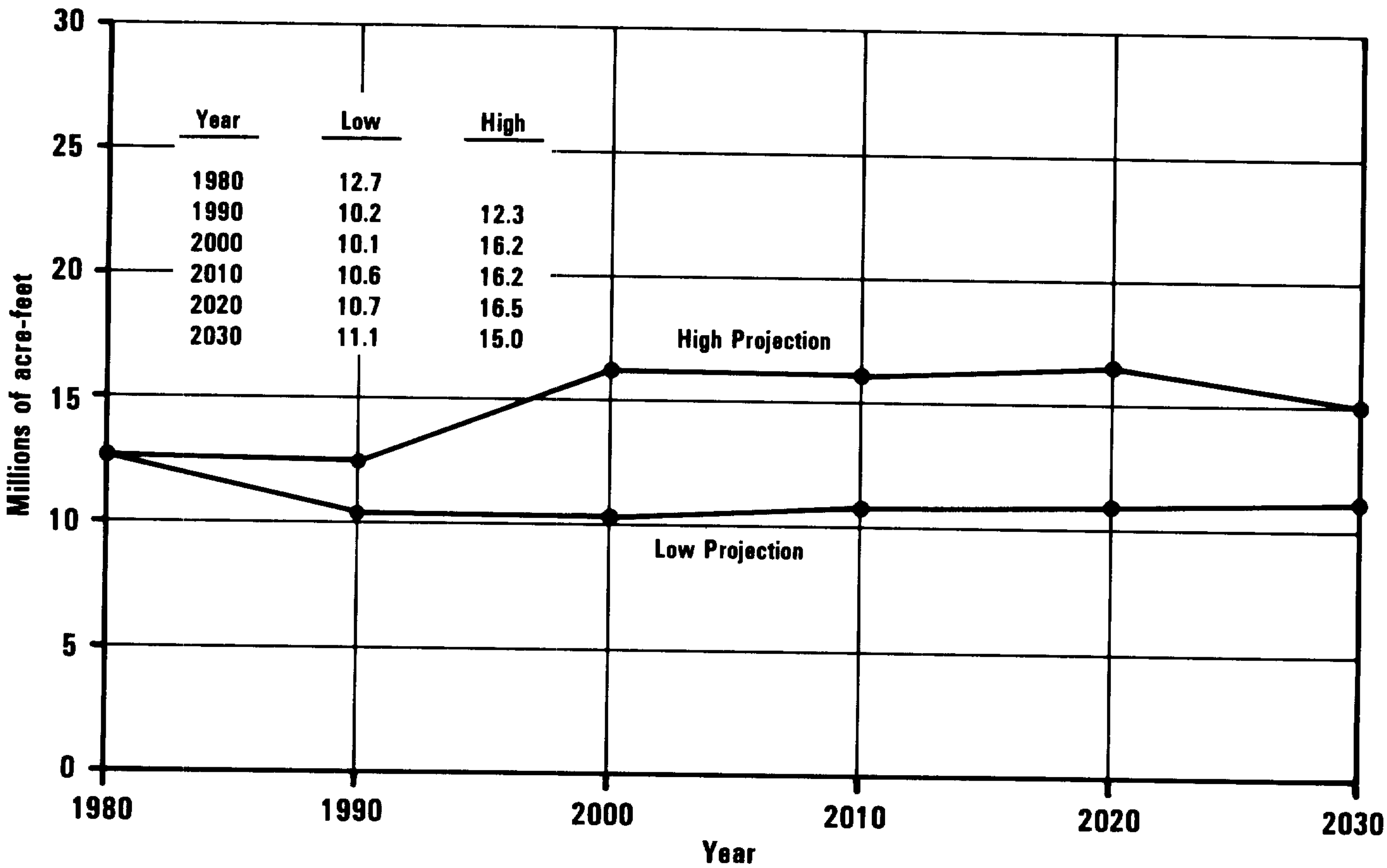


Figure II-10. Projected Irrigation Water Requirements, High and Low Series, 1980-2030

ments is similar to the current distribution with the exception that livestock water use is not expected to increase in the major metropolitan counties.

Table II-7. Livestock Water Use in 1980 with Low and High Projections of Requirements to 2030.

Year	Projected Water Requirements[1] (thousands of acre-feet)
1980[2]	244.0
1990	287.5
2000	331.7
2010	331.7
2020	331.7
2030	331.7

[1]Only one set of projections was made for future livestock water requirements.
[2]Reported and estimated water use in 1980.

Mining Water Demand

Mining activities in Texas include the production of crude petroleum, natural gas, uranium, salt, sulfur, construction materials, and the extraction and processing of lignite for the production of synthetic fuels. In 1980, the Texas mineral industry was foremost in the production of crude petroleum and natural gas in the United States and ranked fifth nationally in the value of output for a wide variety of important nonfuel minerals. Texas is a leading producer of nonmetals (Frasch sulfur, clay, gypsum, salt, stone, and sand and gravel); however, petroleum production accounts for most of the freshwater presently used in the mining sector.

Mining was categorized into fuels, metals, and nonmetals for purposes of projecting the future freshwater needs of this sector of the Texas economy. The principal use of water in mining is for the recovery of petroleum by fluid injection, commonly known as secondary recovery. Both saline and freshwater are used for secondary oil recovery and maintenance of oil reservoir pressure. Estimates contained herein are for freshwater. The development of sand and gravel resources and the recovery of minerals other than petroleum also require the use of freshwater for the separation of desirable materials from by-products and waste; however, consumptive use of freshwater in these operations is small in comparison to requirements for the fuel industry.

The crude petroleum and natural gas producing industries utilized 126 thousand acre-feet in the secondary and enhanced recovery of oil and for natural gas processing out of a total for all mining purposes of 239 thousand acre-feet of freshwater in 1980. Fluid injection operations have increased production from 30 percent in 1965 to around 60 percent in 1980 of the total volume of oil produced within the State. Calculations indicate that an estimated three thousand acre-feet of freshwater will be required in Texas by the year 2030 for secondary and enhanced recovery of oil. Brackish water, saline water, or freshwater can be used for injection operations, and the choice is usually dictated by the economics of water supply and operation and maintenance costs. The projection of water requirements for secondary recovery operations was based on an evaluation of the amount of oil available which can be produced by water injection. Much of the total water requirement for secondary oil recovery can be satisfied by saline water commonly produced with oil and gas in the State, by the recycling of water used in secondary recovery projects, or by locally available brackish or saline waters, principally from ground-water sources.

A significant decrease in water demand for secondary and enhanced oil recovery is the result of depletion of known and projected newly discovered quantities of oil available to be produced, increasing use of saline or brackish waters for pressure maintenance and enhanced recovery operations, and improving technological advances that reduce demand for freshwater.

On account of recent development in international energy markets and declining domestic oil and gas production, synthetic fuels are being seriously considered as a substitute for conventional fossil fuels. Since lignite reserves in Texas are significant, there are tentative plans to construct synthetic fuel plants in the State. With the exception of experimental pilot plants, there were no synthetic fuels operations in Texas in 1980. It is estimated that by the year 2000, however, water use for the production of synfuels should represent 16 percent of State mining water requirements. By the year 2030, synthetic fuels are estimated to be the second largest category of mining water use in the State and to require 33 percent of estimated total mining freshwater needs.

Metal and nonmetal mining activities in Texas accounted for approximately half of mining freshwater use in 1980 and are estimated to represent 60 percent of mining freshwater requirements in 2030. The projected demand in 2030 takes into account the projections of a decline in the production of petroleum and natural gas, significant development of synthetic fuels, and increases in demand for construction materials in the metropolitan areas.

For mining water use, only a single set of projections were made, not a high and low case as in other use categories (Table II-8). In this single projection, mining water requirements, fuels, metals, and nonmetals combined, in

Table II-8. Mining Water Use in 1980 with Projections of Requirements to 2030.

Year	Projected Water Requirements[1] (thousands of acre-feet)
1980[2]	239.0
1990	231.9
2000	267.7
2010	321.4
2020	375.3
2030	387.2

[1]Only one set of projections was made for future mining water requirements.
[2]Reported and estimated water use in 1980.

year 2000 are estimated to be about 268 thousand acre-feet annually and about 387 thousand acre-feet in 2030. These projected demands, compared with the 239 thousand acre-feet used in 1980, indicate an increase of 12 and 62 percent, respectively, in the two future time periods. Mining water projections for each area of the State are presented in Part III.

Hydroelectric Power Water Use

Presently, Texas has 22 hydroelectric power plants with an installed hydroelectric generating capacity of 546 megawatts (Table II-8). In 1980, these facilities provided only about one-half of one percent of the electricity generated in the State. A new 32 megawatt unit is under construction at Amistad Reservoir on the Rio Grande, and several hydroelectric units on the Guadalupe River are being reactivated.

Although water is not consumed (evaporated, etc.) in the generation of hydroelectric power, large volumes of water must flow through the turbine of a plant in order to operate the generator. In 1980, total flow through hydroelectric turbines in Texas exceeded 11 million acre-feet. With the construction of additional reservoirs in Texas, water used for hydroelectric power plants in 2030 is expected to be more than double the current quantity of use; however, such use will be a by-product of other water-using activities, and is not considered an additional consumptive demand upon State water supplies.

Navigation Water Use

Texas navigational facilities are primarily located within the coastal area. Along the Gulf coast there are 12 Texas ports which will accommodate deep-draft vessels (30-45 feet), and 13 Texas ports for shallow-draft vessels (6-14 feet). The Intracoastal Waterway connects ports of Texas to other Gulf and Atlantic states by a protected, shallow-draft channel. Extensions from this canal connect important industrial areas with other coastal navigation channels and sea lanes. Existing and planned navigational facilities in Texas do not have regulated freshwater flow requirements.

There is inland navigation currently on the downstream reaches of the Sabine, Neches, Trinity, Brazos, and Colorado Rivers, but very little water release from reservoir storage is required to maintain adequate navigational depths. Normal streamflows plus impoundment releases for other purposes are expected to continue to satisfy these navigation needs. Also, there is some potential for additional inland navigation on Texas rivers, such as the Cypress, Red, Trinity, San Jacinto, Neches, and Sabine, which would necessitate providing locks and adequate freshwater flows around dams. Streamflow might also be needed to maintain satisfactory navigation depths in these rivers. However, no estimates of the flows needed are presented here because the inland navigation projects are not envisioned in the near future.

Bay and Estuary Freshwater Needs

Texas coastal environments contain natural and man-made resources of significant economic importance to the State. In particular, these areas contribute multiple-use inputs to the Texas economy in several forms that include, but are not limited to: (1) a navigation network of national importance; (2) a resource base of State importance for minerals, seafoods, and recreational opportunities; and (3) a natural source of ecological treatment for many nutritive wastes and by-products. Total annual economic values are at billion dollar levels in each major category such as shipping, oil and gas production, fishing, and recreation and tourism. Freshwater requirements for municipal, industrial, agricultural, and other uses in the coastal areas have been included in Part III of this report. The following discussion identifies inflow relationships and estimates the freshwater needs of Texas bays and estuaries.

Major Estuarine Systems

The coastal bays are estuarine areas where seawater from the Gulf of Mexico mixes with freshwater discharged from Texas streams and rivers to create highly productive and diverse natural environments. Texas has 11 major river basins, 10 with headwaters originating within the State, which are associated with bays and estuaries of primary or secondary importance. There are seven major and several minor estuaries located along the 400 miles of Texas Gulf coastline (Figure II-11). Major bays are contained in the Sabine-Neches, Trinity-San Jacinto, Lavaca-

Table II-9. Hydroelectric Power Plants in Texas, 1980.

Basin	Dam	Reservoir	Capacity (Megawatts)
Red	Denison	Lake Texoma	70[1]
Sabine	Toledo Bend	Toledo Bend	85[2]
Neches	Sam Rayburn	Sam Rayburn	52
Brazos	Morris Sheppard	Possum Kingdom	22.5
	Whitney	Whitney	30.0
Subtotal			54.5
Colorado	Buchanan	Buchanan	36
	Roy Inks	Inks	12
	Alvin Wirtz	LBJ	52
	Max Starke	Marble Falls	32
	Mansfield	Travis	84
	Tom Miller	Austin	14
Subtotal			230
Guadalupe	TP-1	Dunlap	3.6
	Abbot (TP-3)	McQueeny	2.0
	TP-5	Molte	2.5
	H-4	H-4	2.4
	H-5	H-5	2.4
	Seguin	TP-4	2.4
Subtotal			16.1
Rio Grande	Red Bluff	Red Bluff	2.3
	Amistad	Amistad	66.0
	Eagle Pass	(Canal)	9.6
	Falcon	Falcon	31.5
Subtotal			109.4
Texas Total			615.0

SOURCE: Texas Department of Water Resources

[1]Part of the power generated at Denison Dam is sold in Oklahoma.

[2]Part of the power generated at Toledo Bend Dam is sold in Louisiana.

Tres Palacios, Guadalupe, Mission-Aransas, Nueces, and Laguna Madre estuaries. Riverine estuaries that flow directly into the Gulf include those of the Brazos, San Bernard, Colorado, and Rio Grande rivers. Texas estuarine systems are generally characterized as drowned river mouths (the result of an ancient rise in sea level), and are complimented by elongate barrier islands that enclose approximately 1.5 million surface acres of open water bay area and at least an additional 1.1 million acres of marshlands and tidal flats. Scientific and engineering studies have been made on each estuary in recent years to better understand the importance of freshwater to each estuarine system, and for estimation of the seasonal timing and quantities of freshwater flow needed by each estuary.

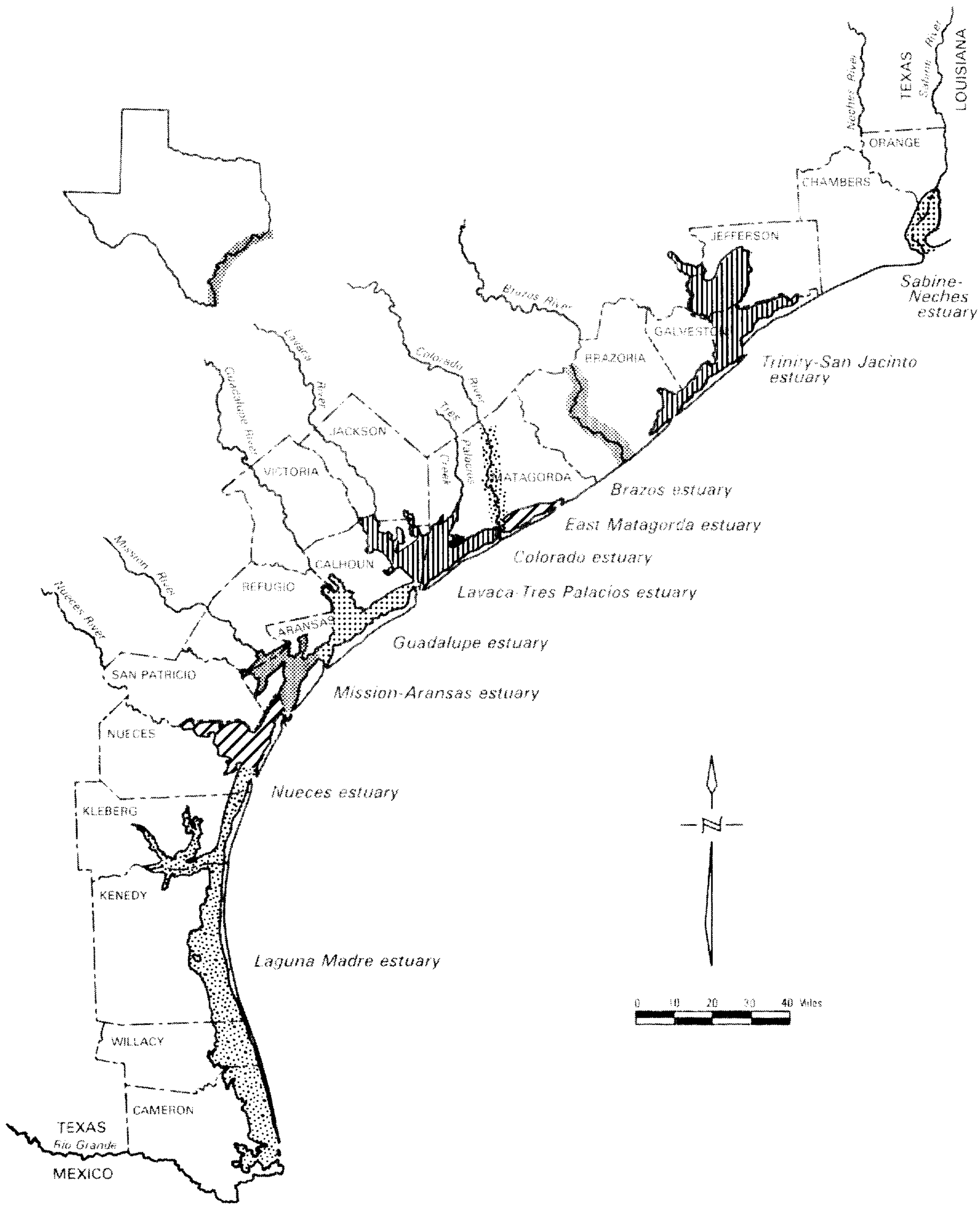


Figure II-11. Location of Texas Estuaries

Freshwater Inflow Factors

The inflow of freshwater is widely recognized as an essential factor in maintaining the biological productivity of Texas bays and estuaries. Virtually all of the coastal fisheries species are considered estuarine dependent, while the estuaries themselves are dependent upon freshwater inflows for nutrients, sediments, and a viable salinity gradient that allows inhabiting organisms to survive, grow, and reproduce. In addition, it is known that periodic estuary flushing by high inflows inundates river delta marshes, stimulates the cycling of nutrients, transports food materials, and removes or limits many pollutants, parasites, bacteria, and viruses harmful to estuarine-dependent organisms. These effects and the relationships among them are described below.

Hydrology

The inflows of fresh surface waters to Texas coastal areas include flows measured at the most downstream gaging station of each Texas stream (called "gaged" flows), and inflows that usually originate as local runoff from rainfall on ungaged coastal watersheds (referred to as "ungaged" flows). Therefore, sources of freshwater flow to Texas estuaries are: (1) gaged inflow from rivers, streams, and creeks, as measured at their most downstream gaging stations before entering the estuaries; (2) ungaged rainfall runoff, primarily from the surrounding coastal basins; (3) return flows, usually from municipal, industrial, and agricultural water users in ungaged areas; and, (4) direct precipitation on the estuary. The measurement or estimation of each inflow source is necessary in order to quantify the relationships among freshwater inflows and changes in the estuarine environments. Historically, total annual freshwater inflow to the seven major Texas estuaries from their combined river and coastal drainage basins has averaged almost 30 million acre-feet per year, but minimum annual gaged river flows have been as little as 4.1 million acre-feet under drought conditions. Freshwater inflow to the estuaries can be diminished by climate, evaporation, ground-water (aquifer) recharge, and consumptive water use. The timing of inflows to the bays can also be affected by these factors. To realize estuarine benefits, freshwater inflows should be at seasonally appropriate levels in each Texas estuary. For example, adequate springtime inflows are important for production of many fish and shellfish species, while high inflows during cold periods can be detrimental to most organisms overwintering in the estuaries.

Circulation and Salinity

The distribution of water quality constituents and living resources in Texas bays is determined to a large extent by the movements of water within the estuarine systems. Perhaps the most direct and apparent effects of freshwater inflow occur as a result of changes related to estuarine salinity. For example, the concentration of salts can interact with other environmental factors to stimulate species-specific biotic responses, such as reproduction or migration. Salinity also affects species adaptation to the environment, species distribution patterns, biological community diversity of the ecosystem, and ultimately species evolution. In addition, the evaluation of upstream water development projects or wastewater discharges into the bays often focuses on changes in the circulation and salinity patterns of Texas bays and estuaries. The effects of freshwater inflow on estuarine circulation and salinity have been studied and the results taken into account for the estimation of freshwater needs.

Nutrients and Water Quality

The biological productivity of Texas estuaries is dependent upon the availability of essential nutrients, including carbon, nitrogen, and phosphorus, as well as trace elements like silicon, potassium, zinc, manganese, and others. In addition, important water quality factors include the presence of sufficient dissolved oxygen for the respiration of aerobic organisms like fish and shellfish, and the absence of toxic chemicals which can limit survival, growth, and reproduction of estuarine-dependent organisms. Fortunately, the water quality of Texas estuaries is generally considered to be good, except in some modified environments such as harbors and ship channels where chronic problems can persist. Nutrients required in large quantities, like nitrogen, are quickly depleted from the coastal environments. Consequently, a deficiency in this essential nutrient can limit the ecosystem's productivity. Three natural sources of nutrients to estuaries are streamflows, rainfall, and seawater exchange, although the latter two are not considered major sources of nutrients to Texas estuaries. Freshwater flows from the rivers and streams that empty into the bays and estuaries of Texas are recognized to be the primary source of nutrients responsible for the biological productivity of the coastal environments.

Critical Periods

Because adequate freshwater flow during critical periods is more beneficial to ecological maintenance than abundant flow during noncritical periods, the time of inflow can be extremely important to Texas bays and estuaries. Biologically, seasonal timing of freshwater inflows can affect the production of associated wetland areas, the utilization of nursery habitats by juvenile fish and shellfish, and the transport of sediments and nutritive food materials (especially detritus) to the estuary. As a result, the freshwater inflow needs of Texas estuaries are not static annual requirements. In fact, dynamic fluctuation about the productive range, seasonally and annually, are both realistic and desirable for the estuaries. However, extended periods where inflow conditions consistently fall below maintenance levels can lead to degraded estuarine environments, loss of important nursery habitats for seafood species, and a substantial reduction in the potential for natural assimilation of organic and nutritive wastes. Critical periods in the life cycles of ecologically or economically important coastal species were also taken into account when estimating the freshwater needs of Texas estuaries.

Primary and Secondary Production

Fundamentally, biological communities are energy-nutrient transfer systems. Primary producers (plants) transfer nutrients and energy to secondary producers (animals) through feeding relationships within an estuary's food web. Each bay and estuary has characteristic plant and animal assemblages. Since these species respond to changes in their environment, such as variations in water quality or the rate of freshwater inflow, they can be useful as indicators of major fluctuations in primary and secondary production, and the general "health" of an estuarine ecosystem. Freshwater needs of the bays and estuaries include levels of inflow that are estimated to maintain the primary and secondary production of Texas coastal environments.

Fisheries

The coastal fisheries may be divided into two major components—finfish and shellfish. Both are harvested in large quantities by sport and commercial fisherman along the Texas coast. Prominent coastal fisheries species include brown shrimp, white shrimp, blue crab, bay oyster, spotted seatrout, red drum (redfish), black drum, croaker, sheepshead, flounder, and sea catfish. Distribution of the finfish catch is approximately 72 percent inshore in Texas bays and 28 percent offshore in the Gulf of Mexico. The shellfish harvest is of an opposite distribution with about 79 percent offshore and 21 percent inshore. However, regardless of where they were caught, virtually all of the Texas coastal fisheries species are considered estuarine-dependent during at least some portion of their life cycles.

Economic and Other Values of Coastal Areas

Texas bays and estuaries are the source of market and nonmarket products and services. For example, some nonmarket values of the coastal environments include the benefits associated with waste assimilation, use as a source of industrial cooling waters, buffering of inland areas from flood and storm impacts, and aesthetic values. Resources which have market values include oil and gas production, shipping, fishing, and recreation and tourism. However, they are not all equally dependent on freshwater inflow to the estuaries for their future use and continuity. Renewable natural resources, such as water and fisheries, can be extracted from the coastal environments for indefinitely long periods of time, if properly managed; whereas, nonrenewable resources like minerals are finite in natural supply and with continuous extraction will ultimately be depleted. Shipping and some tourism are not dependent upon freshwater inflow, but sport and commercial fishing, tourism associated with coastal fishing, hunting, or nature studies, and the food supplies of migratory waterfowl depend on adequate inflows of freshwater.

Commercial Fishing

The commercial harvests of fish and shellfish species dependent on Texas estuaries were recently reported to have totaled about 113 million pounds (over 90 percent shellfish) in 1981, with a direct dockside landings value of $174.8 million. At this level of fishing activity, the total annual economic impact is approximately $544.5 million, which reflects the gross business, personal income, and tax revenue values to the State's economy. The Texas shrimp harvest accounted for 94 percent of the 1981 dockside landings value, and was approximately 36 percent of the total shrimp catch in the United States. Overall, Texas ranks fourth among the states in the value of its commercial seafood landings.

Recreation and Tourism

The environments and abundant natural resources of the bays and estuaries provide a wide variety of recreational opportunities to both residents and visitors of the Texas coast. There are approximately 15 million visitors to the coast each year, but the economic values derived from this tourism are difficult to estimate. Water-oriented recreational activities such as fishing, boating, and swimming are readily available coastwide on the 1.5 million acres of open water bay area. Also, adjacent marsh wetlands and contiguous inland areas contain birds, mammals, and other wildlife resources that provide opportunities for hunting, sightseeing, nature studies, and aesthetic benefits to the public. For example, over two-thirds of the ducks and geese on the central flyway of North America overwinter on the Texas coast, to the enjoyment of thousands of waterfowl hunters. Another recreational activity of both residents and tourists that depends on freshwater inflows to Texas bays and estuaries is sport fishing. It has been estimated that sports fishermen catch between 4 and 10 million pounds of coastal fish annually, with the total economic impact to Texas in 1979 valued at $709 million.

Cultural and Scientific Values

The bays and estuaries are additionally valuable for their cultural and scientific resources. For example, scientific values accrue to the State because it has one of the most diverse estuarine regions in the world. The estuarine systems here vary from the low salinity environments characteristic of the northeast part of the Texas coast, to the extreme, high salinity bays and lagoons of the southwestern coast. In particular, the Laguna Madre is one of only three oceanic, hypersaline (salinity higher than seawater), lagoonal areas known to exist. Cultural resources, such as historical sites and archaeological discoveries, are also common along the Texas coast and link our present cultural heritage to the past. Some living resources, like the Whooping Crane, are rare and endangered, but find safe repository in the natural environments of Texas bays and estuaries.

Estimates of Freshwater Inflow Needs

The physical, chemical, and biological relationships to freshwater inflow were integrated and used to compute the flows needed to meet specific objectives for marsh inundation (nutrient cycling), salinity gradients, and fisheries harvests. These objectives provide a range of options that include the survival, maintenance, and enhancement of Texas bays and estuaries.

Four different levels of inflow were selected for estimation. The long-term ecosystem need (Level I) has the objectives of meeting estimated salinity viability limits and marsh inundation (nutrient cycling) requirements. Summing across the seven major Texas estuaries, the quantity of freshwater needed is an average of 13.6 million acre-feet per year of gaged river flows. By comparison, gaged river flows to Texas estuaries during the 1941 through 1976 historical period have averaged 23.7 million acre-feet per year. Effects of Level I inflows on the coastal fisheries are not projected to be significantly different overall from the average historical harvests, but effects on individual species can vary.

The long-term freshwater need for maintenance of the coastal fisheries (Level II) has the same objectives as Level I, plus requires sufficient inflows to give predicted fisheries harvests at the 1962 through 1976 average levels. The Level II need is estimated to be an average of 9.6 million acre-feet per year of gaged river flows, but does not include flows to Sabine Lake where data were not adequate to make estimates beyond the Level I subsistence need of 5.7 million acre-feet per year.

Level III, the long-term inflow need for enhancement of selected fisheries species also has the same basic objectives as Level I, but additionally includes the objective of providing sufficient freshwater inflows to maximize the harvest of an important fisheries species or species group in each estuary. This level of inflow is estimated at an average of 9.9 million acre-feet per year of gaged river flows to all major Texas estuaries combined, except for the Sabine-Neches estuary where again no estimate was possible. Fisheries production was projected to increase almost 18 percent coastwide with this inflow regime.

Lastly, a short-term freshwater inflow need (Level IV) was computed which has as its objective meeting only the monthly salinity viability limits of estuarine-dependent organisms ecologically characteristic of each estuary. Adding up the 12 monthly estimates for an annual cycle, and summing across all seven major estuaries, gives a short-term minimum inflow need of 4.7 million acre-feet per year. At this minimum level of inflow, Texas coastal fisheries harvests are projected to decline overall by one-quarter to one-half of the average historical production. Estimates of freshwater inflow need for individual estuaries are given in Part III of this report.

Instream Flows

The phrase "instream flow needs" refers to the quantity of water flowing within a natural stream which is necessary to maintain the stream's values for instream beneficial uses that include: (1) navigation, (2) hydropower (3)livestock water, (4) water quality maintenance, (5) maintenance of fish and wildlife habitat, (6) recreation, and (7) aesthetic enjoyment. Traditional and legal differences between instream and offstream uses have historically favored the latter, except for the paramount public right of navigation which is established by the Commerce Clause of the United States Constitution.

Purpose

In Texas, diffuse surface waters which originate from natural precipitation become State waters when they reach a stream watercourse or drainage channel. As property of the State, the waters are subject to the appropriative rights doctrine governing their use. To conserve and properly utilize State waters, current State law prioritizes the beneficial uses in the Texas Water Code. Preference for appropriation is given in the Code as: (1) domestic and municipal, (2) industrial, (3) irrigation, (4) mining, and recovery of minerals, (5) hydroelectric, (6) navigation, (7) recreation and pleasure, and (8) other beneficial uses. Although uses of instream flows are not given the highest preference they are recognized by the Code within beneficial uses (5) through (8). These would implicitly include protection of riverine fish and wildlife, as well as maintenance of freshwater for the bays and estuaries. However, the instream flows needed for divergent beneficial uses cannot be generalized into a single standard. It is inevitable that Texas streams will provide for multiple water uses, and that tradeoffs will occur to obtain maximum benefits from this limited public resource.

Permits issued by the Texas Water Commission provide that State waters can be appropriated for one or more of the previously listed beneficial uses. Some uses are nonconsumptive, such as navigation and hydroelectric power generation, and can be compatible with instream flow needs of fish and wildlife. Other purposes of water use may not be compatible because they are generally offstream consumption uses, such as waters supplied for irrigation, industrial, and municipal activities.

Stream Water Sources

Texas river systems have water sources that include spring-feeding aquifers, ground-water seeps, and return flows from offstream uses. The characteristics of these instream flows are greatly influenced by climatological conditions and human water demands. Since Texas encompasses large arid areas, a significant percentage of State streams exhibit a naturally intermittent flow pattern with extended periods of little or no flow, while other stream segments have historically had their base flows almost constantly supplied by discharges from the State's major and minor aquifers. However, present and future demands on some of these aquifers may exceed the rate of recharge, and can diminish or even result in complete cessation of spring flows.

Return flows from offstream water users are primarily composed of treated effluents and wastewater discharges. These flows must meet water quality standards set by the Texas Department of Water Resources and can serve as a dependable source of water for many of the State's stream segments which ordinarily would cease to flow during dry seasons. Thus, instream benefits have been created for fishing, hunting, and habitat maintenance by these flows.

Instream benefits are also obtained from construction of reservoirs throughout the State. Texas reservoirs have provided benefits to downstream environments through releases for hydroelectric power generation, alleviation of salt water intrusion, recreation, and municipal, industrial, and agricultural water uses. Structural reservoir features, such as multi-level outlet works, can allow selection or blending of discharge waters for optimal water quality. In addition, operational criteria have been established for some reservoirs to provide a minimum continuous instream flow for maintenance of downstream fish and wildlife habitats. Discharge schedules have also been studied for meeting instream recreational demands, as well as maintenance of Texas bays and estuaries, but water rights permits must be issued on the basis of specific conditions in each case.

Parks and Fish Hatcheries Water Needs

Programs in wildlife management have helped to maintain favorable conditions for wildlife populations in Texas. The Texas Parks and Wildlife Department presently operates 17 wildlife management areas within the State for preservation and research purposes. These areas provide aquatic and terrestrial habitat for the large populations of wildlife species native to the various geographical areas of the State.

The fisheries resources of Texas have long provided one of the more popular forms of outdoor recreation, sport fishing. In recent years, efforts of the Fisheries Division of the Texas Parks and Wildlife Department have been directed toward sustaining a balance of fish populations in the reservoirs, streams, and coastal waters which provide habitat for the more popular species sought by sport fishermen. The Department presently operates 11 freshwater fish hatcheries and one saltwater fish hatchery with a total pond area of 532 acres. Water rights for these facilities total more than 14.5 thousand acre-feet annually; this is a nonconsumptive use of water. An expansion of the hatchery systems over the next ten years has been proposed which would require an additional 5,000 to 6,000 acre-feet of water annually. These proposed facilities would be located in areas having sufficient water to meet their needs.

Recreational land resources in Texas include more than two million acres, of which 92 percent is State-owned and operated land. Wildlife management areas administered by the State account for more than 50 percent of the recreational land resources, with the remaining land area including State parks, historical sites, and designated scenic areas. Sufficient water supplies to maintain these established areas are now and can continue to be obtained from locally available sources. However, when locating additional recreation areas, careful attention should be given to the selection of sites having sufficient water rights.

Recreation and Tourism Water Needs

The State's water resources provide an important recreation resource for the people of Texas as well as for out-of-state visitors. Water-oriented recreation facilities in Texas are operated by private developers and public agencies, the latter of which includes the Corps of Engineers, the Bureau of Reclamation, the Texas Parks and Wildlife

Department, Texas river authorities, special districts, and municipalities.

Although recreation is a nonconsumptive use of water, the magnitude of recreational use of the State's water resources is a viable indicator of the value to Texans of these resources for recreational purposes. In 1980, almost 57 million people visited reservoirs in Texas under the management of the U.S. Army Corps of Engineers, representing an increase of approximately 16 million visitors since 1976.

Texas has 184 lakes and reservoirs which have a conservation storage capacity of five thousand acre-feet or more each, and almost one million acres of water surface. These lakes provide a variety of recreational activities ranging from fishing to sightseeing, with fishing, the most popular activity, accounting for more than 48 percent of all visitation in 1980.

The present level of use of water-oriented recreation facilities indicates that as Texas' population increases, the use of water-oriented recreation facilities can be expected to rise significantly. The 1980 Texas Outdoor Recreation Plan (TORP), prepared by the Texas Parks and Wildlife Department, provides a planning guide for meeting future recreational needs throughout the State. By the year 2000, the 1980 Texas Outdoor Recreation Plan estimates that recreation demand for fishing, boating, skiing, and swimming will increase by 227 million annual activity days. Increased demand for these activities will require an additional 51.8 thousand surface acres of reservoirs. Accommodation of this additional requirement is within the total number of water surface acres to be added in Texas by the year 2000.

PART III

CURRENT WATER USE, FUTURE WATER REQUIREMENTS, AND PROPOSED WATER SUPPLY DEVELOPMENT AND WATER QUALITY PROTECTION IN THE RIVER AND COASTAL BASINS OF TEXAS

INTRODUCTORY OVERVIEW

In Parts I and II, water supply and related problems have been identified; State and federal statutes and institutions which govern or impact water resources development and use have been briefly described; planning methodology and planning data have been described; and the importance of water for the economic, environmental, and social well-being of Texas has been presented.

In Part III, analyses of current water use and projections of water requirements and water-related needs to meet the State's foreseeable 50-year future needs are presented. Projections are made of available ground- and surface-water supplies and use of these sources of supply to meet projected needs in each river and coastal basin of the State, including planning subareas as shown in Figure II-5. Water resource development needs and alternatives are assessed with respect to time of need, quantity of water supply, water quality protection needs, and flood protection elements. Each basin analysis draws together local, State, and federal water resource development and potential development into a complete description and accounting for the basin. In effect, the sum of the individual basin analyses and projections represent a statewide overview of the extremely complex and highly fragmented water resources program in Texas. A statewide tabulation of the specific basin analyses has been made (Table III-1).

Attention is given to water rights in the form of a summary of the present structure of surface- and ground-water-law in Texas and the current status of water rights adjudication activities being carried on by the Texas Department of Water Resources under provisions of the Water Rights Adjudication Act of 1967. A summary of the number of appropriative rights, claims, and filings and associated quantities of surface water involved, as of December 31, 1983, is also provided for each river and coastal basin of the State.

On the basis of new and revised projections of population and economic growth and associated water needs, water resource projects considered necessary to meet future needs to the year 2030 and intervening decades are specifically identified and described in the discussion of problems and needs within each river and coastal basin of the State. These include additional or enlarged reservoirs and new or enlarged water-delivery systems to convey raw water supplies from existing or new sources to areas of current or projected need. Existing supplies as well as additional projects identified as necessary to meet projected needs will not provide for any significant expansion of irrigated agriculture in Texas. In fact, because of competition for available supplies, declining ground-water reserves, urban growth, and the necessity to improve management of the State's aquifers through more careful development to avoid land subsidence and saline-water intrusion into the freshwater bearing zones, irrigated agriculture may decline in some areas, particularly in parts of the coastal region and West Central Texas, as well as the High Plains. The problem of sustaining irrigated agriculture in the High Plains is addressed in Part IV.

Figures II-3 and II-4 illustrate the geographic distribution of major and minor aquifers in Texas. A major aquifer is herein defined as one which produces large quantities of water in a comparatively large area of the State, whereas minor aquifers produce significant quantities of water within smaller geographic areas. Minor aquifers are important in that they presently constitute the only significant source of water supply in some regions of Texas. Estimates have been made for each county of the quantities of water in storage in each aquifer, the average annual recharge to each aquifer, and the quantity of water recoverable from storage in each aquifer. Using this information, estimates have been made of the annual long-term quantities of water supply that might be obtained from the aquifers within each county to meet local area water demands.

Table III-1. Population, Current Water Use, With Projected Population and Water Requirements, 1990-2030a/
Statewide

River Basin Zone & Category of Use	1980 Ground Water	1980 Surface Water	1980 Total	1990 Ground Water	1990 Surface Water	1990 Total	2000 Ground Water	2000 Surface Water	2000 Total	2010 Ground Water	2010 Surface Water	2010 Total	2020 Ground Water	2020 Surface Water	2020 Total	2030 Ground Water	2030 Surface Water	2030 Total
Texas																		
Population			14,229.2			17,846.1			21,239.4			24,840.3			29,127.4			34,276.6
Municipal	1,290.3	1,522.9	2,813.2	1,306.1	2,896.3	4,202.4	1,440.3	3,640.3	5,080.6	1550.4	4,383.7	5,934.1	1,636.7	5,316.5	6,953.2	1,604.1	6,573.4	8,177.5
Manufacturing	248.6	1,271.4	1,520.0	167.3	1,955.1	2,122.4	191.2	2,526.7	2,717.9	219.0	3,095.4	3,314.4	255.4	3,823.6	4,079.0	288.1	4,725.6	5,013.7
Steam Electric	53.0	277.0	330.0	71.9	463.1	535.0	175.8	640.9	816.7	239.6	777.4	1,017.0	267.8	949.2	1,217.0	274.1	1,143.4	1,417.5
Mining	178.4	60.7	239.0	137.8	94.1	231.9	120.6	147.1	267.7	142.8	178.6	321.4	155.5	219.8	375.3	156.2	231.0	387.2
Irrigation	8,957.0	3,749.4	12,706.4	8,407.7	3,918.0	12,325.7	11,631.6	4,579.2	16,210.8	11,342.8	4,854.5	16,197.3	11,767.6	4,746.2	16,513.8	9,907.1	5,111.8	15,018.9
Livestock	119.6	124.3	243.9	128.4	159.1	287.5	140.8	190.9	331.7	134.3	197.4	331.7	120.4	211.3	331.7	103.8	227.9	331.7
State Total Water	10,846.9	7,005.7	17,852.6	10,219.2	9,485.7	19,704.9	13,700.3	11,725.1	25,425.4	13,628.9	13,487.0	27,115.9	14,203.4	15,266.6	29,470.0	12,333.4	18,013.1	30,346.5

a/ Population in thousands of persons, water requirements in thousands of acre-feet per year.

Generally speaking, the annual quantity of ground-water supply available is estimated as the average annual recharge plus the estimated annual quantity of water that would be withdrawn from recoverable storage in order to meet projected future annual needs of each area. However, the annual supply estimates from some aquifers have been constrained to the quantities, which if withdrawn, would not result in degradation of the aquifer through salt-water intrusion or other effects or would not result in land subsidence in coastal areas. Estimates for each area are based on water use data recently reported by those who use water from the aquifers of each respective area, and from projections of future annual water demands of each area. In the case of aquifers having very little recharge, the projected future annual supplies decline and the aquifers will ultimately be depleted. The time at which this will occur depends upon the quantities of water withdrawn annually. In other cases, where recharge is greater, the dependable annual ground-water supplies are greater and of longer duration. Exceptional cases are described briefly.

The projected average annual supply available from the High Plains (Ogallala) Aquifer was estimated by imposing a set of projected ground-water demands and are projections of the annual quantities of ground-water withdrawals that the aquifer is hydrologically capable of supplying under the conditions of the demands projected. The annual quantities of supply estimated for this aquifer are not estimates of the aquifer's safe annual yield because of the very low recharge to this aquifer. Given the "High Series" projected demands from 1980 through 2030, the High Plains (Ogallala) Aquifer is estimated to be capable of supplying 234.55 million acre-feet of ground water from storage with 150.93 million acre-feet of water remaining in storage in January, 2031. On an average annual basis the aquifer receives about 438.9 thousand acre-feet of recharge which means that the projected average annual demands are 19 times greater than the average annual recharge to the aquifer.

The projected average annual ground-water supplies available from the Alluvium and Bolson Deposits Aquifers in El Paso County, using projected high case water demands are 143.7 thousand acre-feet in 1990, 181.4 thousand acre-feet in 2000, 219.1 thousand acre-feet in 2010, 208.5 thousand acre-feet in 2020, and 60.0 thousand acre-feet in 2030. (Note: Will not correlate with Table II-1 because the data pertain only to El Paso County.) These annual supplies were estimated using fresh water storage depletion analyses which assumed that only one-half or about 5.38 million acre-feet of the 10.76 million acre-feet of fresh water in storage could be removed without serious ground water quality degradation in both the Hueco Bolson and Mesilla Bolson Aquifers. Under these conditions, availability of fresh water from the two bolson aquifers is reduced after the year 2000, primarily, in about the year 2003 from the Mesilla Bolson Aquifer and in about the year 2020 from the Hueco Bolson Aquifer. Any additional ground water removed from the bolson aquifers would have to be desalted because of its high salinity. The storage depletion analyses for the two bolson aquifers took into consideration that the aquifers would receive about 26,000 acre-feet of average annual recharge and that by 2030 the Hueco Bolson Aquifer would annually receive about 20,000 acre-feet of artificial recharge.

The annual supplies available from the remaining Alluvium and Bolson Deposits Aquifers, the Trinity Group Aquifer, the Carrizo-Wilcox Aquifer and the Capitan Limestone Aquifer through the year 2029 were projected to include the aquifers' average annual recharge plus quantities from storage which could be safely removed without creating adverse effects due to excessive drawdowns and saline-water encroachment. In the year 2030, the safe annual yields of these aquifers would be reduced to their average annual recharge if the use rates projected for the 1980 through 2030 period actually occur.

The annual yield of the Edwards (Balcones Fault Zone) Aquifer in the San Antonio Region was estimated by using a mathematical model of the aquifer in the Guadalupe, San Antonio, and Nueces River Basins. The model analysis indicated that the safe yield of the aquifer in the three basins should be limited to about 425.0 thousand acre-feet per year if satisfactory levels of spring flows from the aquifer are to be preserved. Under a 425.0 thousand acre-feet annual withdrawal rate and a recharge sequence which included a severe drought period, the model analysis indicated that San Marcos Springs would be able to continue flowing and Comal Springs would go dry. However, extreme water-level declines would not occur, and the potential for saline-water encroachment would be greatly reduced. The annual yield for the Edwards (Balcones Fault Zone) Aquifer in the Austin Region (Colorado and Brazos River Basins) is 13.7 thousand acre-feet and is equal to the aquifer's average annual recharge rate within that region. The total projected average annual ground-water supply available from the aquifer, therefore, is 438.7 thousand acre-feet.

For long-range planning purposes, the projected average annual ground-water supplies available through the year 2030 from the Edwards-Trinity (Plateau) Aquifer, the Gulf Coast Aquifer, and the fifteen other minor aquifers are equal to the average annual recharge rates of these aquifers. The quantities of ground-water available from storage in most of these aquifers have not been estimated because sufficient data are not available. The annual yield for the Gulf Coast Aquifer was estimated using an aquifer model analysis in which water-level drawdowns would be constrained in order to minimize land surface subsidence, fault movement, and saline-water encroachment. Ground water available from the Queen City Aquifer in the Trinity, Neches, Sabine, Cypress, and Sulphur River Basins is only suited for irrigation, steam-electric power generation (cooling), mining and stock watering purposes, because this water has inherently high concentrations of iron and high acidity (low pH). Also the ground water available from the Rustler and Blaine Gypsum Aquifers has extremely high concentrations of sulfate, making them suitable only for irrigation purposes.

Many of the major reservoir projects which are urgently needed now, or will be needed before the year 2000, are federal projects which have been authorized by Congress. These projects are identified in the discussions of each river and coastal basin and are listed in Part V. These projects are in various stages of post-authorization planning, design, and construction in accordance with specific provisions of the authorizing documents and established procedures and policies of the federal government and the principal construction agencies for civil works projects. The current status of those authorized federal projects identified is briefly discussed. However, the complexities of implementation of a multipurpose federal project, from authorization to construction, including procedures for local sponsorship, cost-sharing, and contractual procedures, preclude a detailed explanation of the status of each project. Additionally, since most projects must conform to the provisions of the National Environmental Policy Act of 1969 (NEPA), environmental assessments and environmental impact statements for these projects must be prepared in accordance with guidelines established by the Council on Environmental Quality and are in various stages of completion, including public review and comment and public hearing processes.

Other projects for which a clear need has been established to meet current or projected water supply needs are local projects, which are sponsored and financed entirely through local efforts or will receive financial assistance from federal sources or through the Texas Water Development Fund. These projects are in various stages of implementation, ranging from very preliminary planning to construction. The environmental impacts of local projects in the planning and design stage, or which are under construction, and which have received State financial assistance from the Texas Water Development Fund have been assessed or are currently being assessed through methodology described in the Department's Rules.

Reconnaissance-level studies have been performed to identify several alternatives for developing additional water supplies and delivering these supplies from areas of projected surplus to areas which will unquestionably have critical water supply shortages long before the year 2030; however, additional feasibility studies are necessary. Multireservoir and multibasin operation studies utilizing highly specialized and computerized systems analysis approaches are required in order to find potential solutions to some of these problems. Such analyses will be done in cooperation with local sponsors as the need arises. In addition to addressing the physical, hydrologic, and economic feasibility of various alternative water development and conveyance facilities for meeting long-range water supply needs, the mathematical simulation capabilities presently available can be used to address the full range of environmental interactions and consequences of each alternative under consideration.

It is emphasized that this reanalysis and reassessment of Texas water and water-related problems and needs has been based, with few exceptions, upon an analysis of the firm yields of existing, planned, and potential reservoirs in each basin. Through such an analysis, it is assumed that the total dependable supply which each reservoir will yield, under the particular configuration of upstream development imposed upon the basin, is "removed" each year from all reservoirs. Thus, except where consideration has been given to passage or "releases" of water to satisfy specific downstream needs or vested water rights, such an analysis does not provide a true representation of the volume of water diverted from each reservoir for specified uses at any particular point in time—unless, of course, the full dependable yield is actually being diverted and utilized. Streamflow below a reservoir project is a function of the operating criteria for the reservoir, project purposes, and the volume of water diverted for use. For example, water is normally released from the flood-control pool until the reservoir's "normal" operating level is attained. Streamflows within a developed and regulated river basin and the flows available below the most downstream reservoir in the basin at any point in time during a given hydrologic sequence can be estimated with reliable accuracy only through laboriously detailed simulation of the operation of each reservoir in the basin, with projected water demands placed upon each reservoir corresponding with the projected water requirements for the particular period of time. Utilizing existing mathematical modeling capabilities, river basin operation simulations are being carried on for proposed and potential water-resource development configurations and future water-use projections described herein. Existing water rights, as well as water rights adjudication activities, are being given careful consideration in these simulation analyses. These studies are providing estimates—using the current state-of-the-art mathematical simulation techniques—of the volume as well as the temporal and spatial distribution of instream flows and inflows to Texas major estuarine systems in the future.

Financing reservoir development in Texas has historically relied upon federal appropriations, with local commitments to long-term repayment of those costs allocated to project purposes such as water supply, hydroelectric power generation, and certain recreation facilities. The Texas Water Development Fund and local bonding have supplied most of the remaining funds with which water development, including delivery and storage facilities, have been financed in Texas. A brief discussion of current federal cost-sharing policies and procedures, rapidly changing attitudes and programs at the federal level which may significantly alter these policies and procedures, and financing needs and alternative methods of financing to accomplish the necessary water development and management needs in Texas is presented in Part V. The estimated costs of major new reservoir projects considered necessary to meet the water needs of the State are also shown in Part V. These cost estimates also identify the tentative reimbursable costs for water supply in federal multipurpose projects—such costs must be borne by the local sponsor or sponsors of the projects. However, environmental and financial elements are not addressed in empirical detail. The general nature of interactions between water development and management, and the methodology for measuring these environmental interactions and changes, and the types of data required for environmental impact analyses are presented in Part II. Detailed project-by-project and basin-by-basin environmental analyses require significant time and funding and must be done for each project prior to project implementation.

1. CANADIAN RIVER BASIN

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1. CANADIAN RIVER BASIN

BACKGROUND AND CURRENT CONDITIONS

Physical Description

The Canadian River heads in northeastern New Mexico, flows eastward across the Texas Panhandle into Oklahoma, and merges with the Arkansas River in eastern Oklahoma. Major streams joining the Canadian River in Texas are Punta de Agua Creek near the northeast corner of Oldham County, Big Blue Creek near Borger, and Palo Duro Creek 20 miles southwest of Perryton. Total basin drainage area in Texas is about 12,700 square miles. For planning purposes, the Canadian River Basin has been divided into two zones (Figure III-1-1).

Surface Water

Average runoff in the Texas part of the basin during the period 1941 through 1970 was approximately 15 acre-feet per square mile. The average runoff for the 1941-70 period within contributing drainage areas was about 19 acre-feet per square mile. The lowest flows for consecutive years from 1941 through 1970 occurred during three periods. During the years 1952 through 1954, 1963 through 1964, and 1966 through 1967, average runoff was approximately six acre-feet per square mile, two acre-feet per square mile, and two acre-feet per square mile, respectively.

Flooding in the Canadian River Basin is an infrequent occurrence. Floods which do occur are most often of the "flash" variety and are characterized by rapid rise and fall and high flow velocities. Flooding also occurs periodically due to ponding of water in the playa lakes.

The Canadian River at the New Mexico—Texas State line is moderately saline during periods of low flow. The low flow of the main stem generally contains dissolved-solids concentrations ranging from 2,000 to 3,000 milligrams per liter (mg/l). By contrast, runoff from storm events generally contains less than 300 mg/l; however, the discharged weighted average dissolved solids concentrations in the river at the State line generally ranges from 500 to 1,000 mg/l.

Overall, stream quality degrades somewhat as the Canadian River traverses Texas. Although increased streamflow results in a more uniform quality, the discharge-weighted averages of the river remain between 500 and 1,000 mg/l west of Potter County. As the river flows eastward, it cuts through Permian age formations, drains oil and gas producing areas, and receives municipal and manufacturing return flows, all of which locally degrade water quality. The discharge weighted average dissolved solids concentrations of the river just above Lake Meredith is about 1,000 mg/l. Water stored in Lake Meredith in recent years has contained between 300-340 mg/l chloride, 260-300 mg/l sulfate, and 1,000-1,150 mg/l total dissolved solids. Total dissolved-solids concentrations of the river below Lake Meredith generally exceed 1,000 mg/l. In contrast, many tributaries such as Palo Duro Creek, Red Deer Creek, and Rita Blanca Creek have excellent water quality, with dissolved-solids concentrations commonly below 500 mg/l.

Ground Water

The High Plains (Ogallala) Aquifer underlies most of the Canadian River Basin. In 1980, the saturated thickness of the High Plains Aquifer within the basin ranged from about 20 feet to 540 feet. Yields of large-capacity wells average about 700 gallons per minute (gpm); although locally, wells produce up to 1,200 gpm. Generally, the water has less than 1,000 mg/l total dissolved solids. However, in some areas of the basin ground water of the High Plains Aquifer has fluoride concentrations which exceed Environmental Protection Agency—Texas Department of Health primary standards for fluoride.

Slightly to moderately saline water occurs locally in the lowermost saturated deposits of the Ogallala Formation. Development of the aquifer in such areas has caused saline-water encroachment to the wells. Future development of the aquifer within or adjacent to such areas could result in saline-water encroachment.

Population and Economic Development

The population of the Canadian River Basin was reported at 167.5 thousand in 1980. Amarillo is the largest city in the basin with an in-basin population of over 53.2 thousand. The economy of the Canadian River Basin is based on oil and gas production, agriculture and agribusiness, and varied manufacturing activities. Amarillo serves as a regional center for transportation, distribution, and marketing.

Water Use

Municipal water use in the Canadian River Basin totaled 33.4 thousand acre-feet in 1980, of which 87

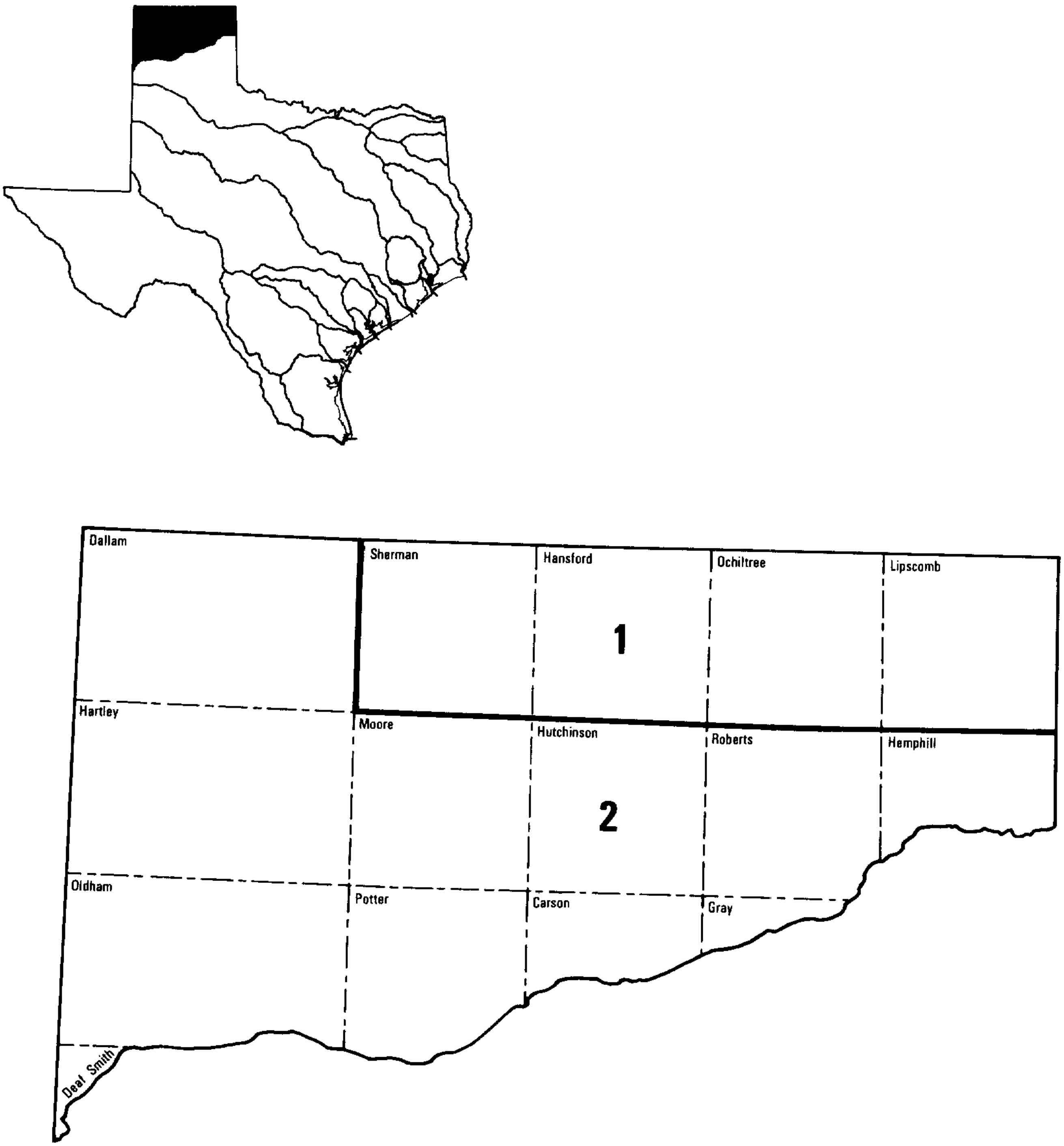

Figure III-1-1. Canadian River Basin and Zones

percent occurred in Zone 2. The City of Spearman used 20 percent and the City of Perryton used 29 percent of the total municipal water use in Zone 1. Almost 41 percent of the municipal water requirement in Zone 2 was attributed to the City of Amarillo (Potter County).

Freshwater use by manufacturing industries in the basin in 1980 was 35.0 thousand acre-feet. Use was almost totally concentrated in Gray, Hutchinson, and Moore Counties of Zone 2. Manufacturing industries in these counties accounted for 90 percent of the total basin use and included the chemicals and petroleum refining industries.

In 1980, there was 1,564 megawatts of installed steam-electric power generating capacity in the Canadian River Basin. Two power plants used a total of 8.7 thousand acre-feet of treated effluent from the City of Amarillo for cooling and other purposes in 1980. In addition, 3.6 thousand acre-feet of ground water was withdrawn from the Ogallala and 2.1 thousand acre-feet of water was diverted from Lake Meredith for steam-electric power production in the Canadian River Basin in 1980. All plants were located in Zone 2 of the Basin.

Irrigated acreage in the basin has increased from 356 thousand acres in 1958 to 1.3 million acres in 1980. Most irrigated acreage produces wheat, grain sorghum, and corn. In 1980, water used for irrigation in the basin totaled 1.7 million acre-feet, of which all but one thousand acre-feet was supplied by ground water from the High Plains Aquifer. Zone 1 of the basin contains about 41 percent of the irrigated acreage, with 534.3 thousand acres using 765.3 thousand acre-feet of water in 1980. Zone 2 contains the remaining 757.2 thousand acres, utilizing 984.2 thousand acre-feet of water in 1980.

Mining water use in the Canadian River Basin is primarily for the extraction of fuels (petroleum and natural gas). An estimated total of 7.0 thousand acre-feet of freshwater was withdrawn for mining in 1980. The most intensive use of water for fuel production is concentrated in Hutchinson County, which accounts for approximately 40 percent of the total mining water use in the basin.

Livestock water use in the Canadian River Basin in 1980 was 15.7 thousand acre-feet. Of this total, ground water provided approximately 12.4 thousand acre-feet, and surface water supplied 3.3 thousand acre-feet. A total of 5.6 thousand acre-feet (4.6 thousand acre-feet of ground water; 1.0 thousand acre-feet of surface water) was used in Zone 1 of the basin and an additional 10.1 thousand acre-feet was used in Zone 2 (7.8 thousand acre-feet of ground water; 2.3 thousand acre-feet of surface water).

Return Flows

In 1980, municipal and manufacturing return flows in the Canadian River Basin totaled 14.6 thousand acre-feet. Zone 1 accounted for only 358 acre-feet of return flows, and the Zone 2 total was 98 percent of the basin total (14.2 thousand acre-feet). Industrial returns comprised approximately 64 percent of the basin total during 1980.

Although a considerable volume of irrigation water is used (1.7 million acre-feet in 1980), irrigation return flows are negligible. Most of the irrigation water applied but not consumed is either reused as tailwater or percolates deeply into the soil.

Current Ground-Water Development

In 1980, approximately 1,825.1 thousand acre-feet of ground water was used in the Canadian River Basin. Of this amount, 774.8 thousand acre-feet was used in Zone 1 and 1,050.3 was used in Zone 2. Practically, all of this ground water was withdrawn from the High Plains (Ogallala) Aquifer which is the primary fresh to slightly saline water-bearing formation in the basin.

Of the 1,825.1 thousand acre-feet of ground water used in the basin, approximately 1,748.5 thousand acre-feet or 96 percent was used for irrigation and about 53.7 thousand acre-feet or 3 percent was used for municipal and manufacturing purposes.

Withdrawals of ground water from the High Plains Aquifer in 1980 are estimated at about 33 times the aquifer's annual natural recharge in Zone 1, and about 18 times the annual natural recharge in Zone 2 of the basin. Annual current and historical pumpages for irrigation purposes have removed large volumes of water from storage, which has caused significant water-level declines.

Current Surface-Water Development

Since 1952, development and use of the surface-water resources of the Canadian River Basin have been governed by provisions of the Canadian River Compact among the states of New Mexico, Oklahoma, and Texas.

There are presently two major reservoirs in the Canadian River Basin in Texas. Rita Blanca Lake is on Rita Blanca Creek and Lake Meredith is on the Canadian River. Rita Blanca Lake, constructed by the U.S. Soil Conservation Service, is operated by Dallam and Hartley Counties for recreational purposes. The reservoir has a capacity of 12.1 thousand acre-feet and a surface area of 524 acres.

Lake Meredith, completed in 1965 by the U.S. Bureau of Reclamation for water supply and flood control, is operated by the Canadian River Municipal Water Authority (CRMWA). The lake, which has 500 thousand acre-feet of conservation storage, 364 thousand acre-feet of sediment storage and 543 thousand acre-feet of storage capacity allocated to flood control, effectively controls all of the developable surface-water resources of the Canadian River in Texas in accordance with provisions of the Compact. Under provisions of the water supply contract between the Canadian River Municipal Water Authority (CRMWA) and the Bureau of Reclamation, the 11 member cities of the Authority are allocated specific annual quantities of water from the reservoir for municipal and manufacturing uses totaling 103 thousand acre-feet annually. In times of water shortage, allocations are adjusted proportionally by the CRMWA Board of Directors. Member cities include Lubbock, Plainview, Amarillo, Borger, Pampa, Levelland, Brownsfield, Slaton, Tahoka, O'Donnel, and Lamesa. Water supplies are conveyed by an east aqueduct, which serves Borger and Pampa; and the main aqueduct, which extends southward through Amarillo and Lubbock to Lamesa. Laterals from the main aqueduct serve Plainview, Slaton, and O'Donnel. The southwest aqueduct extension from Lubbock serves Levelland and Brownsfield.

Under provisions of the water supply contract, annual allotments of water from Lake Meredith to the Cities of Amarillo, Borger, and Pampa in the Canadian River Basin are 38.17, 5.72, and 7.38 thousand acre-feet, respectively. In the water short year 1980, actual deliveries of water through the aqueduct system to Amarillo, Borger, and Pampa were 20.83, 3.87, and 4.35 thousand acre-feet, respectively.

Water Rights

A total of 185,863 acre-feet of surface water was authorized or claimed for diversion and use in the Canadian River Basin as of December 31, 1983 (Table III-1-1). Municipal uses totaled 110,460 acre-feet, or 60 percent of total authorized or claimed water in the basin (Table III-1-2). Zone 2 accounted for the greater portion of authorized or claimed water use, with 173,326 acre-feet, or 94.5 percent of the total amount of water authorized and/or claimed in the basin (Table III-1-2).

Water Quality

The principal water quality problem in the Canadian River Basin is the natural salinity of the Canadian River which adversely affects water stored in Lake Meredith. Water entering the Canadian River from New Mexico contains high levels of dissolved salts. The problem is compounded by the high chloride content contributed by the geologic formations traversed by the Canadian River and its tributaries. In addition, phreatophytes, principally saltcedar, have become established and are spreading in the delta of Lake Meredith and upstream from the lake. During wet periods, saltcedar consume large quantities of water, leaving dissolved chemical constituents as residue. The residue is subsequently redissolved and transported downstream in river flows. Infrequently, high fecal coliform counts occur in some waters of the basin, due in part to large livestock concentrations. Rita Blanca Lake appar-

Table III-1-1. Authorized or Claimed Amount of Water, by Type of Right, Canadian River Basin[1]

Type of Authorization	Number of Rights	Acre-Feet Authorized and Claimed
Permits	30	179,963
Claims	17	5,900
Certified Filings	0	0
Certificates of Adjudication	0	0
Total Authorizations and Claims	47	185,863

[1]The Texas Water Rights Adjudication Act of 1967 authorizes the Texas Department of Water Resources to investigate and determine, with the Court's approval, the nature and measure of water rights for all authorized diversions from surface-water streams or portions thereof except domestic and livestock uses and to monitor and administer each adjudicated water right. These totals incorporate the results of water-rights adjudication in the basin as of December 31, 1983. Certified Filings are declarations of appropriation which were filed with the State Board of Water Engineers under the provisions of Section 14, Chapter 171, General Laws, Acts of the 33rd Legislature, 1913, as amended. Permits are statutory appropriative rights which have been issued by the Texas Water Commission or its predecessor agencies. Claims are sworn statements of historical uses to be adjudicated in accordance with the Texas Water Rights Adjudication Act. A certificate of adjudication is the final result after recognition of a valid right in the adjudication process and is based on a permit, certified filing or claim or any combination of the three.

Table III-1-2. Authorized or Claimed Amount of Water, by Type of Use and Zone, in Acre-Feet, Canadian River Basin

Type of Use	Number of Rights	Zone 1	Zone 2	Total
Municipal	2	10,460	100,000	110,460
Industrial	5	0	51,604	51,604
Irrigation	34	1,215	8,414	9,629
Recreation	6	862	13,308	14,170
Other	1	0	0	0
Total	47[1]	12,537	173,326	183,363

[1]Does not sum due to multipurpose "rights", which may be applied to more than one type of use.

ently suffers no bacteriological problems; however, extensive algal blooms have occurred in the lake.

The quality of water from the High Plains Aquifer in the Canadian River Basin is generally good, although fluoride concentrations locally exceed the Environmental Protection Agency Interim Primary Drinking Water Standards.

Flooding and Drainage

Due to the limited urbanization of the Canadian River Basin, flood damages to urban areas have not been significant. With the exception of the floods in 1941, for which damage estimates are not available, no major floods have occurred in the basin. This is primarily the result of construction of Sanford Dam, completed in early 1965, which created Lake Meredith.

Of the 32 communities which have been designated as having special flood hazards, nine cities are participating in the National Flood Insurance Program. All Participants are in the Emergency Phase of the Program. Due to the limited areas which are susceptible to damaging floods, no concentrated effort has been made to establish 100-year flood elevations in the basin with the exception of the City of Amarillo, which presently has a rate study underway.

Flat topography, low permeability of soils, and lack of adequate natural drainage have produced drainage problems in some areas in the High Plains section of the basin. Many of these areas are visible as playa lakes during wet periods.

Recreation Resources

The two reservoirs in the Canadian River Basin have a combined total of 17.0 thousand surface acres of water available for water-oriented recreation activities. Rita Blanca Lake, the smaller of the two reservoirs with 524 surface acres, is used solely for recreational purposes. Lake Meredith, located 10 miles northwest of Borger, has a surface area of 16.5 thousand acres and serves some of the recreational needs of the people in the Panhandle and Southern High Plains areas.

PROJECTED WATER REQUIREMENTS

Population Growth

The population of the Canadian River Basin is expected to increase 60 percent by the year 2030, from the present 167.5 thousand (1 percent of the State population) to 267.3 thousand (0.8 percent of the State population), as shown in Table III-1-3. A 15 percent increase to 192.8 thousand is forecast from 1980 to the year 2000, and a growth of 39 percent is anticipated for the following 30 years (2000 to 2030).

Population growth in Potter County (part of the Amarillo Standard Metropolitan Statistical Area) is expected to increase 64 percent over the planning period 1980 to 2030. The population of Ochiltree County is expected to increase 19 percent by 2030, from the present 9.6 thousand to 11.4 thousand; and the population in Sherman County should move upward from 3.2 thousand in 1980 to 7.1 thousand by 2030.

Water Requirements

Municipal

Municipal water requirements were projected for two cases of future growth based on both population and per capita water use. Requirements in the Canadian River Basin are projected to increase from the 1980 level of 33.4 thousand acre-feet by 12 to 15 percent by 2000. In the year 2030, water requirements are projected to range from 49.7 to 73.7 thousand acre-feet. Eighty-seven percent of the municipal water requirements in the year 2000 are projected to occur in Zone 2.

Industrial

Manufacturing water requirements in 1980 were 35.0 thousand acre-feet in the Canadian River Basin. Projections of future water requirements for manufacturing purposes were made by decade and for a low and high case for each industrial group. In 1980, over 90 percent of total manufacturing water use was concentrated in five industrial groups: chemicals, petroleum refining, primary metals, paper products, and food products. Because of this concentration, careful attention was given to the future growth outlook for these industries in making the projections.

Manufacturing water requirements in the Canadian River Basin are projected to increase by at least 147 percent (as compared to the State average of 178 percent) by the year 2030. Over 99 percent of the manufacturing water requirements are, and likely will remain, concentrated in Zone 2, which includes part of the Amarillo Standard Metropolitan Statistical Area.

Table III-1-3. Population, Current Water Use, With Projected Population and Water Requirements, 1990-2030[a]
Canadian River Basin

River Basin Zone & Category of Use	1980 Ground Water	1980 Surface Water	1980 Total	1990 Ground Water	1990 Surface Water	1990 Total	2000 Ground Water	2000 Surface Water	2000 Total	2010 Ground Water	2010 Surface Water	2010 Total	2020 Ground Water	2020 Surface Water	2020 Total	2030 Ground Water	2030 Surface Water	2030 Total
Zone 1																		
Population			22.7			23.0			24.9			27.0			30.4			34.4
Municipal	4.4	0.0	4.4	6.0	0.0	6.0	6.7	0.0	6.7	7.3	0.0	7.3	8.2	0.0	8.2	7.0	2.3	9.3
Manufacturing	0.1	0.0	0.1	0.1	0.0	0.1	0.2	0.0	0.2	0.2	0.0	0.2	.3	0.0	0.3	0.3	0.0	0.3
Steam Electric	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.9	0.0	5.9	11.7	0.0	11.7	17.6	0.0	17.6
Mining	1.1	0.0	1.1	0.8	0.0	0.8	0.5	0.0	0.5	0.5	0.0	0.5	.4	0.0	0.4	0.3	0.0	0.3
Irrigation	764.6	0.7	765.3	702.3	0.6	702.9	1,384.8	0.6	1,385.4	1,248.9	0.6	1,249.5	1,016.5	0.7	1,017.2	762.1	0.6	762.7
Livestock	4.6	1.0	5.6	5.1	1.6	6.7	5.9	1.8	7.7	5.4	2.3	7.7	4.5	3.2	7.7	3.4	4.3	7.7
Zone Total Water	774.8	1.7	776.5	714.3	2.2	716.5	1,398.1	2.4	1,400.5	1,268.2	2.9	1,271.1	1,041.6	3.9	1,045.5	790.7	7.2	797.9
Zone 2																		
Population			144.8			160.1			167.9			182.4			205.6			232.9
Municipal	17.6	11.4	29.0	25.2	17.7	42.9	28.1	18.0	46.1	31.7	18.6	50.3	37.4	19.4	56.8	43.4	21.0	64.4
Manufacturing	31.6	3.3	34.9	36.9	9.7	46.6	45.8	12.5	58.3	61.1	8.9	70.0	78.4	6.8	85.2	96.2	6.6	102.8
Steam Electric	3.6	10.8	14.4	1.8	17.1	18.9	18.0	17.1	35.1	24.0	17.1	41.1	29.9	17.1	47.0	35.9	17.1	53.0
Mining	5.8	0.1	5.9	4.7	0.5	5.2	4.3	0.1	4.4	4.4	0.1	4.5	4.5	0.1	4.6	4.6	0.2	4.8
Irrigation	983.9	0.3	984.2	972.2	0.3	972.5	1,674.6	0.4	1,675.0	1,611.7	0.4	1,612.1	1,384.7	0.4	1,385.1	980.9	0.4	981.3
Livestock	7.8	2.3	10.1	8.9	3.1	12.0	10.5	3.5	14.0	9.8	4.2	14.0	8.0	6.0	14.0	6.7	7.3	14.0
Zone Total Water	1,050.3	28.2	1,078.5	1,049.7	48.4	1098.1	1,781.3	51.6	1,832.9	1,742.7	49.3	1,792.0	1,542.9	49.8	1,592.7	1,167.7	52.6	1,220.3
BASIN TOTALS																		
Population			167.5			183.1			192.8			209.4			236.0			267.3
Municipal	22.0	11.4	33.4	31.2	17.7	48.9	34.8	18.0	52.8	39.0	18.6	57.6	45.6	19.4	65.0	50.4	23.3	73.7
Manufacturing	31.7	3.3	35.0	37.0	9.7	46.7	46.0	12.5	58.5	61.3	8.9	70.2	78.7	6.8	85.5	96.5	6.6	103.1
Steam Electric	3.6	10.8	14.4	1.8	17.1	18.9	18.0	17.1	35.1	29.9	17.1	47.0	41.6	17.1	58.7	53.5	17.1	70.6
Mining	6.9	0.1	7.0	5.5	0.5	6.0	4.8	0.1	4.9	4.9	0.1	5.0	4.9	0.1	5.0	4.9	0.2	5.1
Irrigation	1,748.5	1.0	1,749.5	1,674.5	0.9	1,675.4	3,059.4	1.0	3,060.4	2,860.6	1.0	2,861.6	2,401.2	1.1	2,402.3	1,743.0	1.0	1,744.0
Livestock	12.4	3.3	15.7	14.0	4.7	18.7	16.4	5.3	21.7	15.2	6.5	21.7	12.5	9.2	21.7	10.1	11.6	21.7
Basin Total Water	1,825.1	29.9	1,855.0	1,764.0	50.6	1,814.6	3,179.4	54.0	3,233.4	3,010.9	52.2	3,063.1	2,584.5	53.7	2,638.2	1,958.4	59.8	2,018.2

a/ Population in thousands of persons, water requirements in thousands of acre-feet per year.

Steam-Electric Power Generation

Water requirements for steam-electric power production in the Canadian River Basin will continue to increase steadily in the future. During the next 20 years, installation of the projected additional generating capacity will occur in Zone 2, so that by the year 2000 total water requirements will exceed 35 thousand acre-feet per year. By the year 2030, total freshwater requirements for steam-electric power production in the basin are projected to increase an additional 54 percent to 101 percent, low and high case, respectively.

Agriculture

Irrigation

Irrigation water requirements were projected for two cases of change based on improvements in on-farm application efficiencies, reduction in ditch losses, changes in future resource costs and crop prices, and corresponding changes in cropping patterns to reflect more profitable crops. A low case projects demand for water based on the effects of changes in the above variables but with irrigated acreage held constant at 1980 levels in each zone for each future time period; a high case projects demand for water for irrigation constrained only by the requirement that irrigated farming produce a net positive return in excess of that possible from dryland farming and the requirement not to exceed the amount of irrigable soil in each zone. Thus, the projections of demand, low and high cases, based on the irrigation efficiency and market conditions mentioned above, give an estimate of the quantity of water needed for irrigation in each zone, at each decadal point for which projections were made. These projections of demand are compared to the projected supply of water locally available. When projected demand exceeds projected supply, the difference is a measure of shortage at that point in time.

Irrigation water requirements in the Canadian River Basin are projected to increase from the 1980 level of 1.7 million acre-feet by a projected maximum 75 percent by the year 2000 in the high case, declining 3 percent in the low case. In the year 2030, water requirements in the basin are projected to decline to 1.7 million acre-feet annually, in the high case, to irrigate 1.2 million acres.

Zone 1 is projected to account for about 45 percent, and 44 percent of total basin irrigation requirements in 2000 and in 2030 respectively; Zone 2 is projected to account for about 55 and 56 percent of the total in the high case.

A range of 0.7 to 1.4 million acre-feet and 1.0 to 1.7 million acre-feet of irrigation requirements is projected in Zones 1 and 2 by 2000. By 2030, the range is from 0.7 to 0.8 million acre-feet and 1.0 to 1.1 million acre-feet annually in Zones 1 and 2.

Livestock

Livestock water requirements within the basin are projected to increase from 15.7 thousand acre-feet in 1980 to 21.7 thousand acre-feet annually by 2000. In 1980, in Zone 1, livestock used 5.6 thousand acre-feet and 10.1 thousand acre-feet in Zone 2. By 2030, approximately 21.7 thousand acre-feet of water will be required to satisfy livestock needs in the basin annually, with an estimated 7.7 thousand acre-feet required in Zone 1 and 14.0 thousand acre-feet needed in Zone 2.

Mining

Mining water use in 1980, primarily oil and gas recovery, totaled 7.0 thousand acre-feet in the Canadian River Basin. These requirements are projected to decrease to 5.1 thousand acre-feet by 2030, due to a decline in quantities of potential oil to produce. The Canadian River Basin proportion of total State mining water use, three percent in 1980, is expected to decline to one percent by 2030.

Navigation

No navigation facilities are planned in the Canadian River Basin.

Hydroelectric Power

There are no hydroelectric power generating facilities planned in the Canadian River Basin.

WATER SUPPLY PROJECTS AND MEASURES TO MEET FUTURE BASIN NEEDS

Ground-Water Availability and Proposed Development

The ground-water availability through the year 2030 for the High Plains (Ogallala) Aquifer was estimated by imposing a set of total ground-water demands on a digital ground-water model of the aquifer developed by the Texas

Department of Water Resources in 1982. The model analysis provided the following annual amounts of ground water available from the High Plains Aquifer within the Canadian River Basin from 1990 through 2030 by decade: 1.73 million acre-feet in 1990, 3.13 million acre-feet in 2000, 2.99 million acre-feet in 2010, 2.55 million acre-feet in 2020, and 1.94 million acre-feet in 2030. The model analysis also estimated that from 1980 through 2030 approximately 110 million acre-feet of ground water would be removed from storage, and that of the 99 million acre-feet remaining in recoverable storage in the year 2031 about 32 million acre-feet would remain in the "caprock" (tillable) area and 67 million acre-feet would remain in the "breaks" (nontillable) area of the basin. Within the Canadian River Basin, the High Plains Aquifer receives on an average annual basis about 82.8 thousand acre-feet of recharge. The High Plains Aquifer is the only major fresh to slightly saline water-bearing formation within the Canadian River Basin. Very small, minor amounts of ground water may be available from thin alluvial deposits along the flood plain of the Canadian River and from Mesozoic and Paleozoic rocks in the southwestern portion of the basin where the Ogallala Formation has been removed by erosion in the Canadian River Valley.

The projected annual ground-water use within the Canadian River Basin by decade from 1990 through 2030 is expected to be from 1.76 to 3.15 million acre-feet per year (Table III-1-4). The approximate average annual projected ground-water use within the basin is expected to be about 2.44 million acre-feet per year. Of the 2.44 million acre-feet of average annual projected use, practically all is expected to be from the High Plains (Ogallala) Aquifer.

Surface-Water Availability and Proposed Development

An assessment of the available future water resources in the Canadian River Basin indicates that in all decades beginning in 2000, the basin will experience significant water shortages (Table III-1-4, Figure III-1-2). The surface-water export in Table III-1-4 is for municipal and manufacturing purposes outside of the basin.

Water requirements in Zone 1 of the basin will not exceed available ground- and surface-water resources until after 2030 (Table III-1-5, Figure III-1-3). Shortages amounting to 30.8 thousand acre-feet and 143.8 thousand acre-feet per year (Table III-1-6, Figure III-1-4) are projected to occur in Zone 2 in 2000 and 2030, respectively. The water use category expected to experience these shortages is irrigated agriculture. Water shortages in the basin occur primarily due to the decline in available ground-water resources beginning around the year 1990. Total water shortages in the basin for irrigation increase from 6.2 thousand acre-feet in year 1990 to 147.0 thousand acre-feet in the year 2030.

The continued suitability of water from Lake Meredith for municipal and manufacturing purposes is potentially threatened by increasing salinity of the water in the lake. Salt concentrations in Lake Meredith have, during drought periods, reached levels considered undesirable for drinking water by the U.S. Public Health Service and the Environmental Protection Agency. The U.S. Bureau of Reclamation is studying the feasibility of the development of a pumping and surface storage system to control the flow of brine from artesian aquifers which contribute saline inflows to the Canadian River upstream of Lake Meredith. Such a control system is needed now to protect the water quality of Lake Meredith from further deterioration.

The arid nature of the Canadian River Basin limits the future surface-water resources that can be developed. Because of local interest in developing a supplemental surface-water supply in the area, considerable study has been given to a potential reservoir on Palo Duro Creek, a principal tributary of the North Canadian River. Following creation of the Palo Duro Water Authority by the 56th Legislature, the Authority conducted feasibility studies of potential reservoir sites on Palo Duro Creek. Subsequently, in 1974 the Authority obtained a permit from the Texas Water Rights Commission for construction of a 60.9 thousand acre-feet capacity reservoir on Palo Duro Creek several miles north of Spearman in Hansford County. The reservoir would provide municipal supplies, serve recreational needs of the area, and provide some flood-control benefits along Palo Duro Creek below the dam. The project would have a dependable yield of approximately 10.5 thousand acre-feet annually. Construction of Palo Duro Reservoir will depend upon final decisions of local interests and development of financing arrangements. Project sponsors are currently planning the reservoir and expect to have it constructed by 1990.

Water Quality Protection

A water quality management plan for the Canadian River Basin has been developed pursuant to the requirements of the federal and State Clean Water legislation. The purpose of the plan is to provide information for use in protecting and improving water quality. The plan serves as a basic element in the State's overall water quality strategy and provides guidance in establishing priorities for construction grants for waste treatment facilities, permitting of wastewater facilities, revision of stream standards, and other program activities.

Table III-1-4. Water Resources of the Canadian River Basin, With Projected Water Supplies and Demands, 1990-2030[1]

	Water Supply					Water Demand				Surplus or Shortage		
Decade	In Basin	Intra-Basin	Return Flow	Import	Total	In Basin	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	1757.8	—	—	—	1757.8	1764.0	—	—	1764.0	.0	(6.2)	(6.2)
Surface Water	103.0	—	18.0	.0	121.0	44.5	—	66.2	110.7	10.3	.0	10.3
Total	1860.8	—	18.0	.0	1878.8	1808.5	—	66.2	1874.7	10.3	(6.2)	4.1
2000												
Ground Water	3146.7	—	—	—	3146.7	3179.5	—	—	3179.5	.0	(32.8)	(32.8)
Surface Water	103.0	—	18.3	.0	121.3	47.6	—	71.7	119.3	2.0	.0	2.0
Total	3249.7	—	18.3	.0	3268.0	3227.1	—	71.7	3298.8	2.0	(32.8)	(30.8)
2010												
Ground Water	2975.1	—	—	—	2975.1	3010.0	—	—	3010.0	.0	(35.9)	(35.9)
Surface Water	103.0	—	18.6	.0	121.6	44.6	—	74.2	118.8	2.8	.0	2.8
Total	3078.1	—	18.6	.0	3096.7	3055.6	—	74.2	3129.8	2.8	(35.9)	(33.1)
2020												
Ground Water	2493.1	—	—	—	2493.1	2584.5	—	—	2584.5	.0	(91.4)	(91.4)
Surface Water	103.0	—	19.1	.0	122.1	43.3	—	74.5	117.8	4.3	.0	4.3
Total	2596.1	—	19.1	.0	2615.2	2627.8	—	74.5	2702.3	4.3	(91.4)	(87.1)
2030												
Ground Water	1811.4	—	—	—	1811.4	1958.4	—	—	1958.4	.0	(147.0)	(147.0)
Surface Water	113.6	—	19.6	.0	133.2	47.0	—	74.7	121.7	11.4	.0	11.4
Total	1925.0	—	19.6	.0	1944.6	2005.4	—	74.7	2080.1	11.4	(147.0)	(135.6)

[1] Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions

Intra-Basin: A transfer of water among zones within a river basin.
Import: A transfer of water from another river basin.
Return Flows: Wastewater returned to a natural stream channel that can be recaptured at a downstream point.
Export: A transfer of water to another river basin.

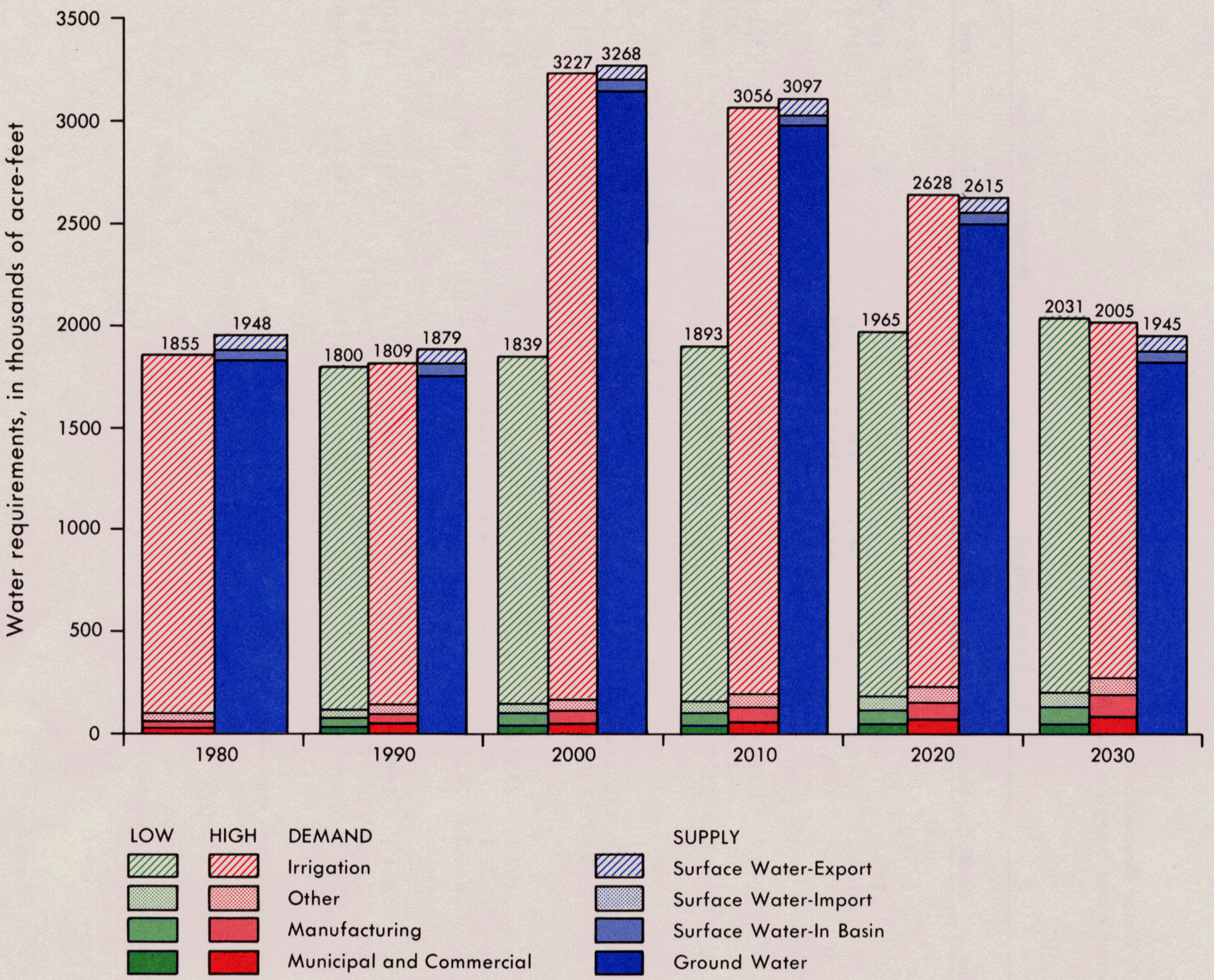

Figure III-1-2. Reported Use and Supply Source, With Projected Water Supplies and Demands, Canadian River Basin, 1980-2030

Construction costs associated with municipal wastewater collection treatment facilities needs have been estimated to be approximately $37.6 million for the planning period of 1980 to the year 2000. These costs are estimated for the entire Canadian River Basin with approximately $34.6 million required in Zone 2, while approximately $3 million is projected for Zone 1. All costs are in January 1980 dollars and are subject to revision as new data become available. The list of projects, with project costs for 1982-1989, at 1980 prices, is shown in Appendix B.

Additional water quality management costs, such as for control of oil and gas, agricultural, and industrial pollutants, cannot be estimated at this time, but are believed to be increasing.

Flood Control Measures

Lake Meredith is the only major flood-control reservoir in the Canadian River Basin. The reservoir has 543.2 thousand acre-feet of flood-control storage. The U.S. Army Corps of Engineers is currently studying the basin to evaluate water-resource problems and needs. The objective of the study is to develop a comprehensive integrated

Table III-1-5. Water Resources of the Canadian River Basin, Zone 1, With Projected Water Supplies and Demands, 1990-2030[1]

	Water Supply					Water Demand				Surplus or Shortage		
Decade	In Zone	Intra-Basin	Return Flow	Import	Total	In Zone	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	714.3	—	—	—	714.3	714.3	—	—	714.3	.0	.0	.0
Surface Water	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Total	714.3	.0	.0	.0	714.3	714.3	.0	.0	714.3	.0	.0	.0
2000												
Ground Water	1398.1	—	—	—	1398.1	1398.1	—	—	1398.1	.0	.0	.0
Surface Water	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Total	1398.1	.0	.0	.0	1398.1	1398.1	.0	.0	1398.1	.0	.0	.0
2010												
Ground Water	1268.2	—	—	—	1268.2	1268.2	—	—	1268.2	.0	.0	.0
Surface Water	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Total	1268.2	.0	.0	.0	1268.2	1268.2	.0	.0	1268.2	.0	.0	.0
2020												
Ground Water	1041.6	—	—	—	1041.6	1041.6	—	—	1041.6	.0	.0	.0
Surface Water	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Total	1041.6	.0	.0	.0	1041.6	1041.6	.0	.0	1041.6	.0	.0	.0
2030												
Ground Water	790.7	—	—	—	790.7	790.7	—	—	790.7	.0	.0	.0
Surface Water	10.6	.0	.0	.0	10.6	2.2	.0	.0	2.2	8.4	.0	8.4
Total	801.3	.0	.0	.0	801.3	793.0	.0	.0	793.0	8.4	.0	8.4

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions
- Intra-Basin: A transfer of water among zones within a river basin.
- Import: A transfer of water from another river basin.
- Return Flows: Wastewater returned to a natural stream channel that can be recaptured at a downstream point.
- Export: A transfer of water to another river basin.

plan of improvement for the Canadian River Basin. An interim report on the feasibility of a multipurpose project on Palo Duro Creek in Hansford County, near Spearman, Texas has been completed and is under review by the Corps' Southwestern Division. The project would provide standard project flood protection.

In the Canadian River Basin, 20 floodwater-retarding structures are planned for construction in Zone 2 under the U.S. Department of Agriculture—Soil Conservation Service Watershed Management Program. None are planned in Zone 1. There were no such structures in the basin as of October 1980.

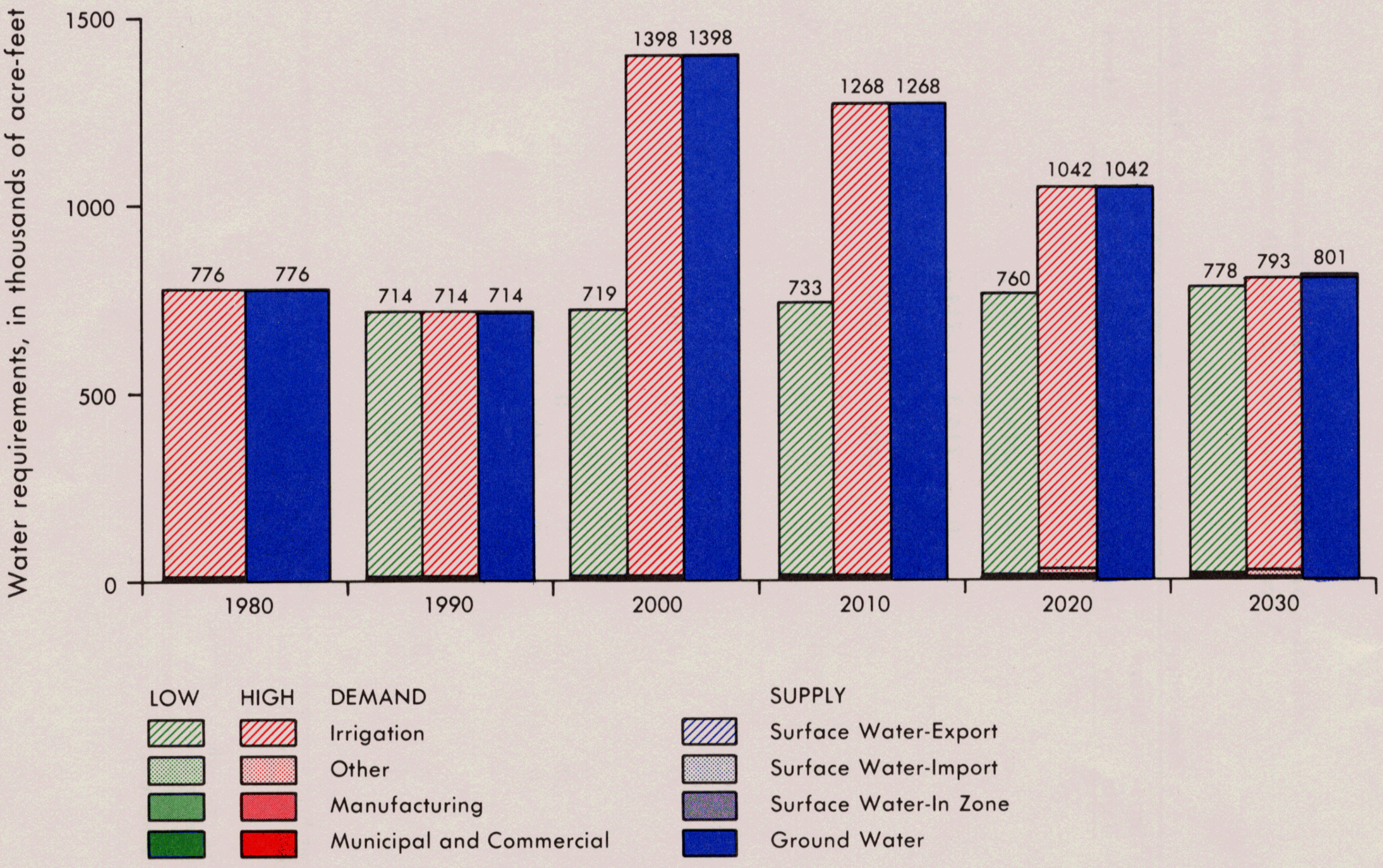

Figure III-1-3. Reported Use and Supply Source, With Projected Water Supplies and Demands, Canadian River Basin, Zone 1, 1980-2030

Table III-1-6. Water Resources of the Canadian River Basin, Zone 2, With Projected Water Supplies and Demands, 1990-2030[1]

	Water Supply					Water Demand				Surplus or Shortage		
Decade	In Zone	Intra-Basin	Return Flow	Import	Total	In Zone	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	1043.5	—	—	—	1043.5	1049.7	—	—	1049.7	.0	(6.2)	(6.2)
Surface Water	103.0	.0	18.0	.0	121.0	44.5	.0	66.2	110.7	10.3	.0	10.3
Total	1146.5	.0	18.0	.0	1164.5	1094.2	.0	66.2	1160.4	10.3	(6.2)	4.1
2000												
Ground Water	1748.6	—	—	—	1748.6	1781.4	—	—	1781.4	.0	(32.8)	(32.8)
Surface Water	103.0	.0	18.3	.0	121.3	47.6	.0	71.7	119.3	2.0	.0	2.0
Total	1851.6	.0	18.3	.0	1869.9	1829.0	.0	71.7	1900.7	2.0	(32.8)	(30.8)
2010												
Ground Water	1706.9	—	—	—	1706.9	1742.8	—	—	1742.8	.0	(35.9)	(35.9)
Surface Water	103.0	.0	18.6	.0	121.6	44.6	.0	74.2	118.8	2.8	.0	2.8
Total	1809.9	.0	18.6	.0	1828.5	1787.4	.0	74.2	1861.6	2.8	(35.9)	(33.1)
2020												
Ground Water	1451.5	—	—	—	1451.5	1542.9	—	—	1542.9	.0	(91.4)	(91.4)
Surface Water	103.0	.0	19.1	.0	122.1	43.3	.0	74.5	117.8	4.3	.0	4.3
Total	1554.5	.0	19.1	.0	1573.6	1586.2	.0	74.5	1660.7	4.3	(91.4)	(87.1)
2030												
Ground Water	1020.7	—	—	—	1020.7	1167.7	—	—	1167.7	.0	(147.0)	(147.0)
Surface Water	103.0	.0	19.6	.0	122.6	44.7	.0	74.7	119.4	3.2	.0	3.2
Total	1123.7	.0	19.6	.0	1143.3	1212.4	.0	74.7	1287.1	3.2	(147.0)	(143.8)

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions
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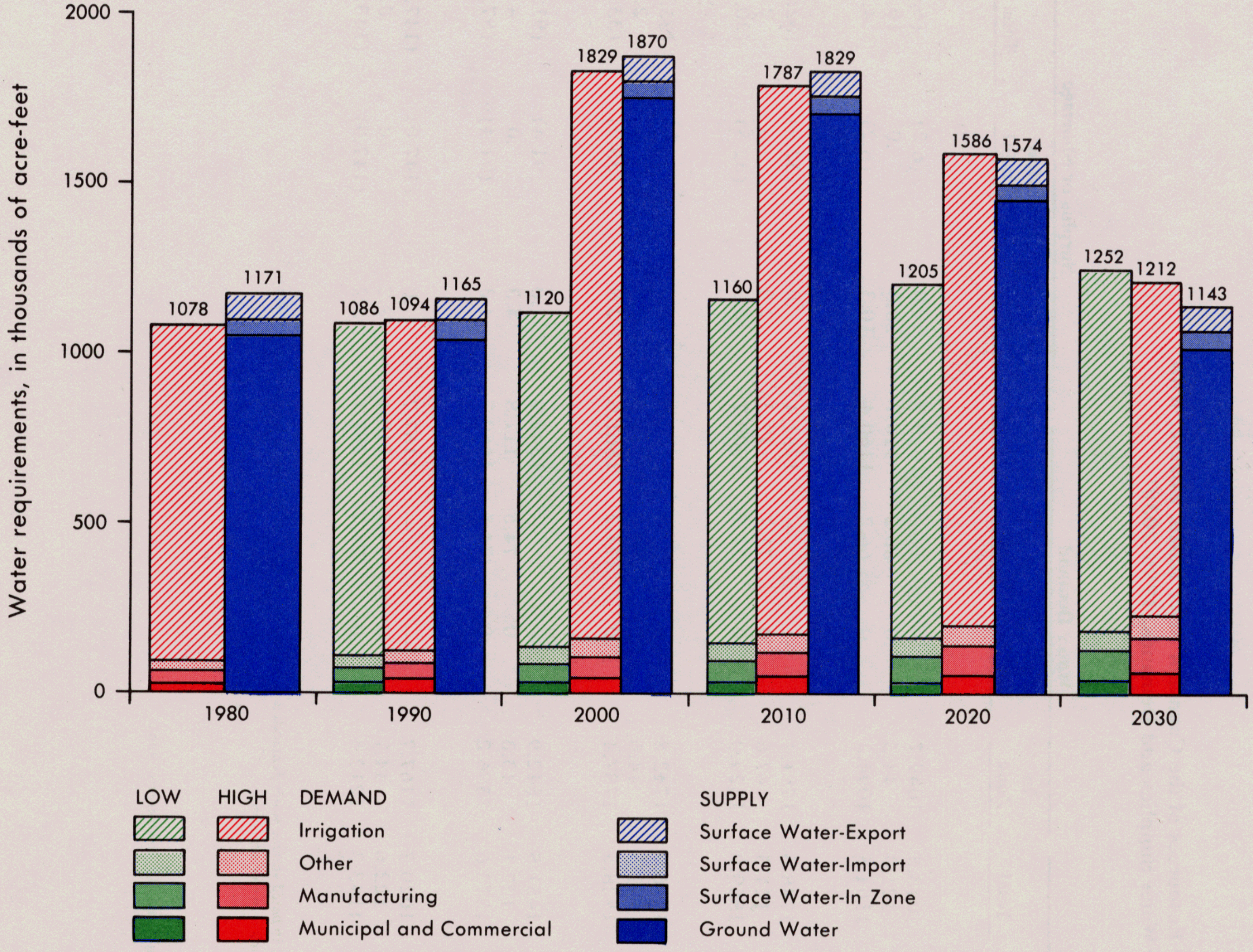

Figure III-1-4. Reported Use and Supply Source, With Projected Water Supplies and Demands, Canadian River Basin, Zone 2, 1980-2030

2. RED RIVER BASIN

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2. RED RIVER BASIN

BACKGROUND AND CURRENT CONDITIONS

Physical Description

The Red River Basin is bounded on the north by the Canadian River Basin and on the south by the Brazos, Trinity, and Sulphur River Basins. Beginning in the High Plains of eastern New Mexico at an elevation of about 4,800 feet, the Red River flows eastward and forms the northern boundary of Texas east of the Panhandle. The river leaves Texas near Texarkana where the elevation of the streambed is about 250 feet. Total basin drainage area is 48,030 square miles, of which 24,463 square miles is in Texas. The North Fork of the Red River forms near Pampa and the Salt Fork of the Red River forms about 26 miles east of Amarillo. Both forks exit Texas into Oklahoma and join the Red River, individually, about 17 miles north of Vernon, Texas. Palo Duro Creek forms near Canyon, Texas and becomes Prairie Dog Town Fork to the east, which in turn becomes the Red River at the 100th meridian. The Red River Basin has been divided into three zones for planning purposes (Figure III-2-1).

Surface Water

The average annual runoff in the basin from 1941 through 1970 was about 203 acre-feet per square mile of contributing drainage area. The lowest flows occurred during the period 1952-56 and 1963-67. From 1952 through 1956, the average annual runoff was 110 acre-feet per square mile, while from 1963 through 1967 the average annual runoff was 95 acre-feet per square mile.

Major flooding occurs infrequently on the upper branches and primary tributaries of the Red River in the drier High Plains region. However, localized "flash" flooding, characterized by rapidly rising and falling peak discharges and high flow velocities, occurs within the region. Progressing eastward through the Red River Basin, flood characteristics change as annual rainfall increases and wide, shallow stream channels become more wooded. Floods rise for several hours after intense rainfall and usually remain out of the banks for several hours.

Extreme variations in chemical quality occur in streams in the Red River Basin in Texas. In the eastern, high-rainfall part of the basin, tributaries carry water containing less than 100 milligrams per liter (mg/l) total dissolved solids, while in the western part of the basin many streams are highly saline and the water is unsuitable for most beneficial uses.

Under low-flow conditions, waters of the lower reaches of the Prairie Dog Town Fork Red River, Pease River, and Wichita River are highly saline, frequently exceeding 25,000 mg/l total dissolved solids, 3,000 mg/l sulfate, and 10,000 mg/l chloride. These high salt loads are derived principally from salt springs and seeps. The average dissolved-solids concentration of water in Lake Kemp is about 3,000 mg/l, of which 700 mg/l is sulfate and 1,200 mg/l is chloride. Beaver and Buffalo Creeks, tributaries of the Wichita River, are periodically affected by drainage from oil fields, but otherwise contribute water of good quality. Despite dilution by floodwaters, the water of the Wichita River averages more than 2,000 mg/l total dissolved solids at the mouth. Water of the Little Wichita River is of excellent quality. The average dissolved-solids concentration is about 400 mg/l.

The quality of the main stem of the Red River gradually improves downstream, but near Gainesville the concentration of dissolved solids between 1977 and 1980 ranged from 850 to 4,000 mg/l, with an average of 2,500 mg/l. Lake Texoma, on the main stem, receives good quality inflows from the Washita River in Oklahoma. The resulting dilution reduces the average concentration of total dissolved solids in water discharged from the lake to about 1,000 mg/l.

Below Lake Texoma, waters of all tributaries of the Red River are low in dissolved solids, thus improving the quality of the main stem. At De Kalb, Texas, the average concentration of dissolved solids in the Red River is about 900 mg/l.

Ground Water

The High Plains (Ogallala) Aquifer underlies most of the upper Red River Basin. The Ogallala Formation is the most productive water-bearing unit of the High Plains Aquifer in Texas. In 1980, the saturated thickness of the High Plains Aquifer within the basin ranged from about 20 feet to 420 feet. Yields of large-capacity wells average about 500 gallons per minute (gpm); although locally wells produce up to 1,100 gpm. Generally, the water has less than 1,000 mg/l total dissolved solids. However, in some areas of the basin, water of the High Plains Aquifer has fluoride concentrations which exceed Environmental Protection Agency—Texas Department of Health primary standards for fluoride.

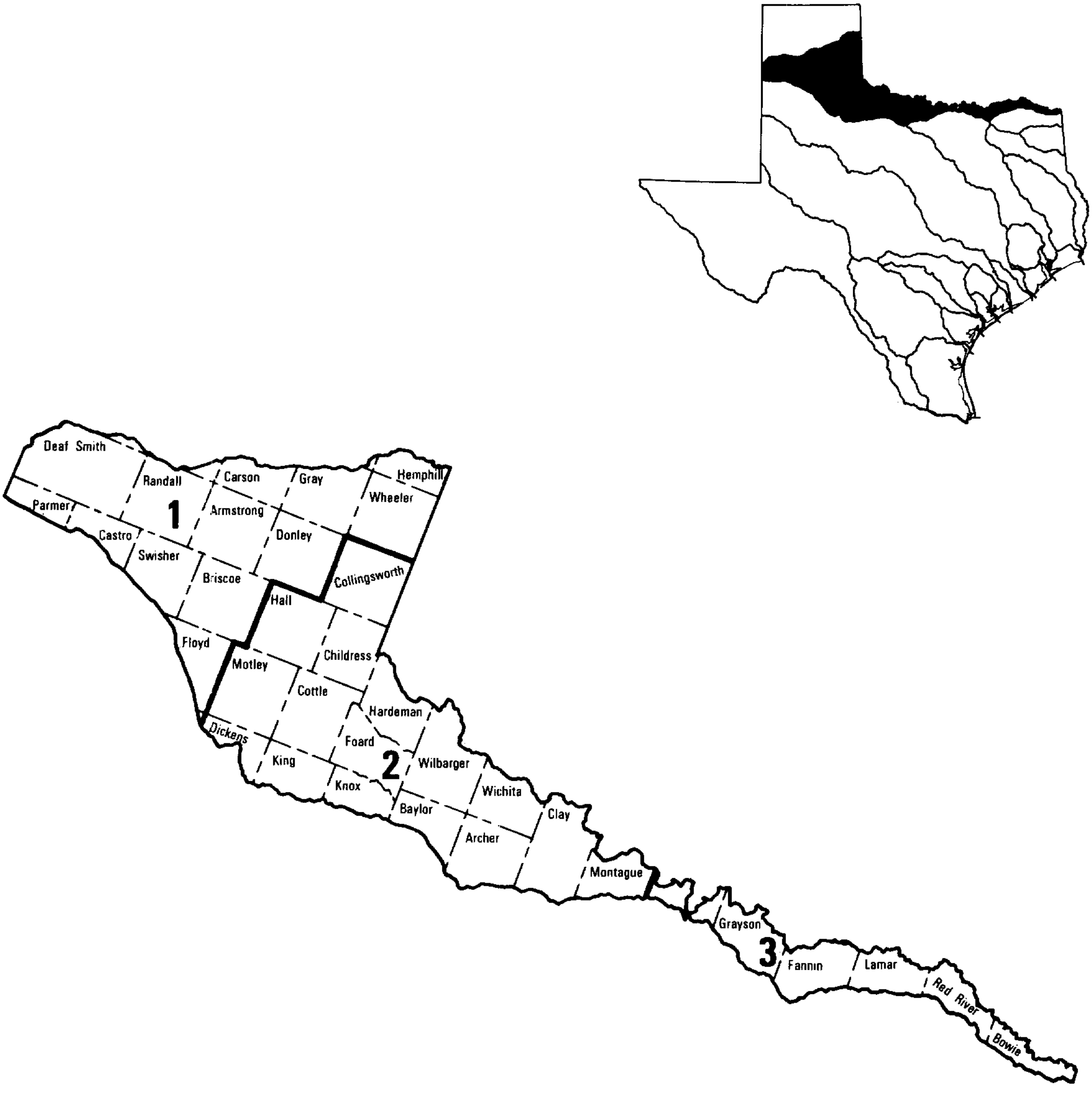

Figure III-2-1. Red River Basin and Zones

The Alluvium Aquifer produces water in local areas in the central part of the Red River Basin. Generally, total thickness is 100 feet or less, but locally it ranges up to about 360 feet. Saturated thickness is commonly less than 50 feet, with a maximum of about 150 feet. Yields of high-capacity wells average 300 gpm, but locally wells produce up to 1,300 gpm. Water in the aquifer is fresh over most of the area, but in some locations is slightly saline.

The Trinity Group Aquifer extends over the eastern and east-central parts of the basin. Total thickness ranges from approximately 400 feet to more than 1,000 feet. Yields of large-capacity wells average 325 gpm; locally wells produce up to 700 gpm. Water in the aquifer generally contains less than 1,000 mg/l total dissolved solids, but salinity increases downdip and toward the east.

The Blaine Gypsum Aquifer occurs in the west-central part of the Red River Basin. Total thickness ranges up to about 250 feet. Yields of high-capacity wells average 400 gpm but locally wells produce up to 1,500 gpm. Water in the aquifer is of relatively poor quality, generally ranging from 2,000 to more than 5,000 mg/l total dissolved solids.

The Woodbine Aquifer occurs in the eastern part of the basin. Total thickness ranges from about 400 to 600 feet. Yields of large-capacity wells average 175 gpm; locally, wells produce up to about 700 gpm. Water in the aquifer generally contains less than 1,000 mg/l total dissolved solids, but salinity increases downdip.

The Blossom Sand Aquifer also extends through the eastern part of the basin. Total thickness ranges up to approximately 400 feet. Yields of high-capacity wells range up to about 650 gpm, but average well yields are significantly lower. Water in the aquifer generally contains from about 500 to more than 2,000 mg/l total dissolved solids.

The Nacatoch Sand Aquifer occurs in Bowie County in the far eastern part of the basin. Total thickness ranges from 350 feet to 500 feet. The aquifer produces usable-quality water to a depth of about 800 feet. Well yields range up to a maximum of about 500 gpm. Water in the aquifer generally contains from 400 to 1,000 mg/l total dissolved solids, with salinity increasing downdip.

Highly mineralized ground waters occur locally in the upper half of the Red River Basin. In these areas, depletion of storage within these aquifers will cause highly mineralized ground waters to invade the depleted fresh to slightly saline ground waters.

Population and Economic Development

The population of the Red River Basin was reported to be 506.0 thousand in 1980. Amarillo is the largest city in the basin with an in-basin population of over 95.9 thousand. It is followed in size by Wichita Falls, which has a population of 94.2 thousand; Sherman, Denison, Hereford, and Vernon all have populations of 12 thousand or more.

The economy of the area is based on oil and gas production, agriculture and agribusiness, manufacturing, retail trade, and tourism. In the western portion of the basin, there is extensive crop irrigation. Wichita Falls serves as a retail trading center and the Sherman-Denison area is a leading manufacturing and trade center serving the north Texas and southern Oklahoma region.

Water Use

Municipal water use in the Red River Basin totaled 98.4 thousand acre-feet in 1980. Zone 1 accounted for 38 percent, Zone 2 consumed 39 percent, and Zone 3 used 23 percent of the basin total.

Cities using significant quantities of municipal water in Zone 1 in 1980 were Hereford, Friona, Amarillo (58 percent of Zone 1 total), and Tulia; Wichita Falls was the largest user in Zone 2 (45 percent of the zone total), and the Cities of Denison, Sherman, and Paris accounted for over 61 percent of municipal water use in Zone 3. Over the basin, 19 percent of the total municipal water use (18.4 thousand acre-feet) was used by rural population or by cities of less than one thousand population.

Manufacturing industries in the Red River Basin used 17.2 thousand acre-feet of freshwater during 1980. Fifty-five percent of this amount originated in Zone 1, while 16 and 29 percent of the total was used in Zone 2 and Zone 3, respectively. Food and kindred products was the major water-using industrial category in Zone 1. Manufacturing freshwater use in Zone 2, however, occurred predominantly in Wichita County where a relatively large variety of manufacutring industries used moderate quanitites of freshwater. In Zone 3, almost the entire use (5.0 thousand acre-feet) occurred in Grayson County, whose major industries were the manufacture of food products, electrical machinery, and scientific instruments.

In 1980, there was 1,144 megawatts of steam-electric power generating capacity in the Red River Basin.

All plants used surface water for cooling, and together they consumed about 9.2 thousand acre-feet of water. This included 6.3 thousand acre-feet of estimated net natural evaporation from cooling reservoirs. In addition, 136 acre-feet of ground water was used for power plant operations.

Irrigation development in the Red River Basin in Texas is largely in the High Plains area (Zone 1). About 1.2 million acres was irrigated in the basin during 1980 using 1.4 million acre-feet of water. About 87 percent of the irrigated acreage was located in Zone 1. Of the approximately 1.2 million acre-feet of irrigation water used in Zone 1 during 1980, all except 2.4 thousand acre-feet was supplied by the High Plains (Ogallala) Aquifer.

In the North-Central Texas area (Zone 2), about 111.0 thousand acres was irrigated in 1980 using 143.6 thousand acre-feet of water. The Alluvium Aquifer and the Blaine Gypsum Aquifer supplied 86.7 thousand acre-feet of this total. Surface water supplied 56.9 thousand acre-feet of on-farm use, most of which was supplied from Lake Kemp and Lake Diversion on the Wichita River.

About 38.3 thousand acre-feet of water was used for irrigation in Zone 3 in 1980. Approximately 92 percent of the Zone 3 irrigation use was from surface-water sources.

Petroleum and natural gas production in the Red River Basin accounted for approximately 87 percent of the 1980 estimated total mining freshwater use of 2.7 thousand acre-feet. The largest freshwater withdrawals for fuel production occurred in Zone 1, with 1.1 thousand acre-feet. Major areas of mining water use are concentrated in Gray County, which accounts for approximately 29 percent of the total basin mining water use.

Livestock water use in 1980 in the basin totaled 33.4 thousand acre-feet. About 20.0 thousand acre-feet was used in Zone 1, 9.1 thousand in Zone 2, and the remainder was used in Zone 3.

There is 70 megawatts of installed hydroelectric power generating capacity at Denison Dam.

Return Flows

In 1980, municipal and manufacturing return flows in the Red River Basin totaled 43.0 thousand acre-feet.

In Zone 1 of the Red River Basin, irrigation return flows are negligible. Any excess irrigation water applied is generally either reused as tailwater or percolates into the soil.

In Zone 2, the areas irrigated from ground-water supplies contribute negligible amounts of irrigation return flows. An estimated 10.5 thousand acre-feet of return flows (35 percent of surface-water use) originated in Zone 2 in 1980. In-stream losses by seepage and evapotranspiration deplete most of these return flows above Lake Texoma.

In 1980, about 2.6 thousand acre-feet of return flows was estimated to originate in Zone 3 of the basin.

Current Ground-Water Development

In 1980, approximately 1,347.0 thousand acre-feet of ground water was used in the Red River Basin. Of this amount, 1,226.7 thousand acre-feet was used in Zone 1, 99.4 thousand acre-feet in Zone 2, and 20.9 thousand acre-feet in Zone 3 of the basin. Practically all of the ground water used in 1980 in Zone 1 of the basin was withdrawn from the High Plains (Ogallala) Aquifer. In Zone 2, most of the ground water used in 1980 was from the Seymour Alluvial Aquifer. Most of the ground water used in Zone 3 was from the Woodbine and Trinity Group Aquifers.

Of the 1,347.0 thousand acre-feet of ground water used in the basin approximately 1,264.3 thousand acre-feet or 94 percent was used for irrigation and about 61.6 thousand acre-feet or about 4 percent was used for municipal and manufacturing purposes.

Withdrawals of ground water in 1980 in Zone 1 from the High Plains Aquifer are estimated at about 22 times the aquifer's annual natural recharge. Annual current and historical pumpages for irrigation purposes have removed large volumes of water from storage which has caused significant water-level declines.

In 1980 within Zone 2, small overdrafts of ground water from the Seymour Alluvial Aquifer for irrigation purposes occurred in Collingsworth, Foard, and Wilbarger Counties.

Within Zone 3 of the basin, overdrafts of ground water for mainly municipal purposes occurred in the Trinity Group Aquifer in Cooke and Grayson Counties, in the Woodbine Aquifer in Grayson County, in the Nacatoch Aquifer in Bowie County, and in the Blossom Aquifer in Fannin, Lamar, and Red River Counties.

Current Surface-Water Development

Since December 1980, Texas use of water in the Red River Basin has been subject to the Red River Compact.

There are 23 major reservoirs in the Red River Basin of Texas. Of this total, 4 projects are located in Zone 1, 11 in Zone 2, and 8 in Zone 3.

Zone 1 of the Red River Basin is served principally from ground-water sources; however, important surface-water projects have been developed locally. Mackenzie Reservoir, located on Tule Creek in Briscoe County, is owned by the Mackenzie Municipal Water Authority. Member cities include Floydada and Lockney in the Brazos River Basin and the Cities of Silverton and Tulia in the Red River Basin. No diversions were made from the project in 1980 because water conveyance and treatment facilities had not been constructed. It is anticipated that all future water needs of the member cities will be supplied through the facilities of the Authority.

Greenbelt Reservoir, located in Donley County, is owned by the Greenbelt Municipal and Industrial Water Authority. Member cities include Clarendon and Hedley in Zone 1, and Childress, Crowell, Memphis, Quanah, and Wellington in Zone 2. Total diversions from Greenbelt Reservoir in 1980 totaled slightly over 4.4 thousand acre-feet, of which about 715 acre-feet was used in Zone 1 and the remainder delivered to cities in Zone 2.

Bivins Lake, owned by the City of Amarillo, is used for aquifer recharge, Buffalo Lake, owned by the U.S. Fish and Wildlife Service is no longer in use because of inadequacy of the dam structure.

The City of Amarillo, part of which is located in the Red River Basin, is a member of the Canadian River Municipal Water Authority which delivered 20.83 thousand acre-feet of water to the city in 1980 through its aqueduct system from Lake Meredith in the Canadian River Basin.

Existing major reservoirs in Zone 2 are Baylor Creek, Electra, Kemp, Diversion, Santa Rosa, North Fork Buffalo Creek, Lake Wichita, Lake Kickapoo, Arrowhead, and Farmers Creek. The City of Wichita Falls owns and operates Lakes Wichita, Kickapoo, and Arrowhead, and is co-owner of Lakes Kemp and Diversion with the Wichita County Water Improvement District No. 2. These projects serve the needs of the City of Wichita Falls and provide municipal and manufacturing supplies for much of Wichita, Archer, and Clay Counties. Lake Wichita is not currently being used because of the inadequacy of the dam structure. Lakes Kickapoo and Arrowhead are the principal sources of surface-water supply for the Wichita Falls area. Lakes Kemp and Diversion supplied 55.5 thousand acre-feet of water for irrigation purposes in 1980. Other reservoirs in Zone 2 supply local needs. Baylor Creek Reservoir was constructed by the City of Childress for a municipal water supply; however, no water was used from this source in 1980. North Fork Buffalo Creek Reservoir is owned by the Wichita County Water Control and Improvement District No. 3 and supplies most of the municipal water used by the City of Iowa Park. Electra Reservoir is owned by the City of Electra and supplements the city's ground-water supply. Santa Rosa Reservoir is owned by the W.T. Waggoner Estate and is used for livestock watering and oil and gas secondary recovery operations. Farmers Creek Reservoir, owned and operated by the North Montague County Water Supply District, supplies the City of Nocona and other areas of Montague County.

One element of the Arkansas-Red Basins Chloride Control Project, Truscott Brine Reservoir located in Knox County on the South Fork of the Wichita River, has been completed by the U.S. Army Corps of Engineers.

Major reservoirs in Zone 3 are Moss, Texoma, Randell, Bonham, Coffee Mill Creek, Pat Mayse, Crook, and Valley. Hubert H. Moss Lake is owned and operated by the City of Gainesville in the Trinity River Basin. No water has been used from the project; however, it is anticipated that future requirements of the Gainsville area will be served from the project. Lake Bonham is owned by the Bonham Municipal Water Authority. In 1980, 1.4 thousand acre-feet of water was diverted from the project for municipal and manufacturing purposes for the City of Bonham. Pat Mayse Reservoir is a multiple-purpose project constructed by the U.S. Army Corps of Engineers for flood control and water supply. The City of Paris, located partially in the Sulphur River Basin, has purchased the conservation storage space in the reservoir to augment the city's supply from Lake Crook. In 1980, 12.7 thousand acre-feet was diverted from the two projects for municipal and manufacturing purposes in the City of Paris as well as other areas of Lamar County in both the Red and Sulphur River Basins.

Lake Texoma, located on the main stem of the Red River, was constructed by the Corps of Engineers as a multiple-purpose project to include flood control, hydroelectric power generation, water supply, and recreation. The City of Denison, Texas Power and Light Company, Atlantic Richfield Co., Texaco, Inc., and the Red River Authority have contracts with the Corps of Engineers for conservation storage capacity. In addition, the City of Sherman has the authority under P.L. 85-146 to contract for water-supply storage, although no contract has yet been consummated. Lake Randell, owned by the City of Denison for a municipal water supply, is also used for regulating diversions from Lake Texoma. In 1980, about 6.1 thousand acre-feet of water was diverted from Lake Randell for municipal and manufacturing uses in the City of Denison and other areas of Grayson County. Valley Lake, owned and operated by Texas Power and Light Company, is also supplemented by diversions from Lake Texoma to maintain a constant operating level for steam-electric power plant operation. The remaining major reservoir in Zone 3 of the Red River Basin, Coffee Mill Creek Lake, is owned by the U.S. Department of Agriculture and is used for recreation.

Surface water utilized for municipal and manufacturing purposes in the lower reach of Zone 3 of the Red River Basin is supplied largely from Lake Wright Patman in the Sulphur River Basin.

Water Rights

The total quantity of surface water authorized or claimed for diversion and use in the Red River Basin was 678,825 acre-feet as of December 31, 1983 (Table III-2-1). Municipal use totaled 312,923 acre-feet, or 46.1 percent of the basin total (Table III-2-2). Zone 2 has the largest quantity of authorized and claimed water in the basin with 418,791 acre-feet, or 61.7 percent of the total amount of water authorized and/or claimed in the basin (Table III-2-2).

Water Quality

A general water quality problem in the Red River Basin is the excessive dissolved-solids concentrations prevalent in most of the streams. These high concentrations are caused in large part by the presence of salt water springs and outcrops of gypsum. Salt water springs are located in the western portion of the basin in the upper reaches of the Wichita River, the North and South Forks of the Pease River, and on the Little Red River which is a tributary to the Prairie Dog Town Fork of the Red River. Gypsum outcrops are found in the area ranging westward from Wichita County to the High Plains caprock escarpment. The water from these areas is usually very high in dissolved solids and occasionally contains chemical concentrations comparable to those found in sea water.

The lower portion of the Wichita River and McKinney Bayou experience occasional low dissolved oxygen and elevated fecal coliform levels. These conditions are primarily due to the discharge of treated wastewater and, in the case of McKinney Bayou, are complicated by the naturally low reaeration capacity of the stream.

Flooding, Drainage, and Subsidence

Reliable estimates of monetary damages due to historical flooding in the basin are generally unavailable. Most of the damages from floods occur in localized areas, for which flood damages estimates have not been made. However, the Corps of Engineers has compiled flood histories for several federal projects within the basin. Floods in 1954, 1955, and 1957 on the Wichita River caused an estimated $4 million in damages. During the period 1950-71, six floods caused an estimated $395 thousand in damages on Big Pine Creek, and during the period 1950-62 floods caused an estimated $313 thousand in damages on Sanders Creek.

Table III-2-1. Authorized or Claimed Amount of Water, by Type of Right, Red River Basin[1]

Type of Authorization	Number of Rights	Acre-Feet Authorized and Claimed
Permits	245	571,009
Claims	161	22,407
Certified Filings	4	85,409
Certificates of Adjudication	0	0
Total Authorizations and Claims	410	678,825

[1]The Texas Water Rights Adjudication Act of 1967 authorizes the Texas Department of Water Resources to investigate and determine, with the Court's approval, the nature and measure of water rights for all authorized diversions from surface-water streams or portions thereof except domestic and livestock uses and to monitor and administer each adjudicated water right. These totals incorporate the results of water-rights adjudication in the basin as of December 31, 1983. Certified Filings are declarations of appropriation which were filed with the State Board of Water Engineers under the provisions of Section 14, Chapter 171, General Laws, Acts of the 33rd Legislature, 1913, as amended. Permits are statutory appropriative rights which have been issued by the Texas Water Commission or its predecessor agencies. Claims are sworn statements of historical uses to be adjudicated in accordance with the Texas Water Rights Adjudication Act. A certificate of adjudication is the final result after recognition of a valid right in the adjudication process and is based on a permit, certified filing or claim or any combination of the three.

Table III-2-2. Authorized or Claimed Amount of Water, by Type of Use and Zone, in Acre-Feet, Red River Basin

Type of Use	Number of Rights	Zone 1	Zone 2	Zone 3	Total
Municipal	45	19,620	206,443	86,860	312,923
Industrial	17	2,721	51,081	53,157	106,959
Irrigation	309	14,575	142,159	32,059	188,793
Mining	10	1,045	4,771	100	5,916
Recreation	46	32,818	6,277	17,079	56,174
Other	4	0	8,060	0	8,060
Total	410[1]	70,779	418,791	189,255	678,825

[1]Does not sum due to multipurpose "rights", which may be applied to more than one type of use.

In recent years, floods in Amarillo in 1978, 1979, and 1981; Wichita Falls in 1979 and 1980; and Sherman in 1981 along with other minor floods throughout the basin produced 201 flood insurance claims for flood damages amounting to approximately $1.6 million. Flooding in October 1981 also brought a Presidential disaster declaration to Grayson County resulting in expenditures of approximately $642 thousand by various federal agencies to offset flood damages in the Red River Basin.

To date, 57 incorporated cities have been designated as having one or more flood hazard areas within their boundaries. Maps have been prepared which identify the areas subject to inundation by the 100-year flood. Thirty-one of the designated cities have adopted minimum flood plain management standards in compliance with the National Flood Insurance Program. In the Cities of Sherman and Wichita Falls, detailed flood insurance studies have been completed. Detailed studies are also underway in the Cities of Canyon, Lake Tanglewood, Burkburnett, Iowa Park, and Pleasant Valley. Completion of these studies will make additional layers of flood insurance coverage available to local residents and will also provide 100-year flood elevation data to the cities for use in future planning and growth.

Drainage problems exist throughout the entire Red River Basin. In the High Plains region, numerous depressions in the generally flat terrain collect storm runoff and form the playa lakes. Playa lake areas pose problems to lands under cultivation. In the lower part of the basin below Lake Texoma, drainage problems occur in alluvium-filled bottomlands.

Land subsidence caused by withdrawals of ground water from the various aquifers is not a problem within the Red River Basin. However, the potential for locally significant subsidence exists within the basin in the area of the Blaine Gypsum Aquifer.

Recreation Resources

There are 22 reservoirs in the Red River Basin with capacities of 5 thousand acre-feet or more. These 22 reservoirs provide over 159 thousand surface acres of water for recreational purposes. Zone 3 of the basin, contains over 101 thousand of the surface acres, with Lake Texoma accounting for 88 percent of the zone total. Lake Texoma, located in Texas and Oklahoma, offers numerous water-oriented recreation opportunities as indicated by the recorded recreation use of the reservoir which totaled more than 12.0 million visits by recreationists during 1980. An additional 1.0 million visits were recorded in 1980 at Pat Mayse Reservoir, located in Zone 3.

PROJECTED WATER REQUIREMENTS

Population Growth

The population of the Red River Basin is projected to increase 82 percent by the year 2030, from 506.0 thousand in 1980 to 919.7 thousand in 2030. A 23 percent growth, to over 624 thousand is anticipated from 1980 to the year 2000, and a gain of 47 percent is forecasted for the remainder of the planning period (2000 to 2030). In comparison, state population is projected to increase 49 percent and 62 percent, respectively, over the same time period (Table III-2-3).

In 1980, Zone 2 population was 38 percent of the total basin population, and this figure is not expected to change by 2030. In contrast, Zone 1 percentage of the basin population increases from 35 percent in 1980 to 36 percent in 2030. Over the projection period, the population in Zone 3 of the basin grows at a slower rate than the basin average (70 percent compared to 79 percent), and its share of basin population declines from 27 percent to 25 percent.

The growth in Zone 1 of the Red River Basin is attributable largely to expected expansion of economic activity in Randall (part of the Amarillo Standard Metropolitan Statistical Area) and Deaf Smith (which includes the City of Hereford) Counties.

Almost all of Zone 2's population growth occurs in Wichita County (part of the Wichita Falls SMSA).

Of the six counties partially in Zone 3 of the Red River Basin, Cooke and Lamar Counties are expected to grow faster than the basin average (95 and 90 percent respectively, from 1980 to 2030 compared to 79 percent). Grayson County accounts for a large portion of the total projected population increase in this zone (an increase of 52 thousand people out of a total zone gain of 95 thousand).

Water Requirements

Municipal

Municipal water requirements are projected for two cases of future growth based on both population and per capita water use. Water requirements in the Red River Basin are projected to increase from the 1980 level of 98.4 thousand acre-feet by a projected maximum of 59 percent by the year 2000. In the year 2030, water requirements are

Table III-2-3. Population, Current Water Use, With Projected Population and Water Requirements, 1990-2030a/
Red River Basin

River Basin Zone & Category of Use	1980 Ground Water	1980 Surface Water	1980 Total	1990 Ground Water	1990 Surface Water	1990 Total	2000 Ground Water	2000 Surface Water	2000 Total	2010 Ground Water	2010 Surface Water	2010 Total	2020 Ground Water	2020 Surface Water	2020 Total	2030 Ground Water	2030 Surface Water	2030 Total
Zone 1																		
Population			178.8			206.3			228.2			254.7			289.4			332.3
Municipal	25.7	11.3	37.0	32.0	23.2	55.2	35.0	26.7	61.7	41.4	27.5	68.9	51.0	27.6	78.6	63.0	27.5	90.5
Manufacturing	8.6	0.8	9.4	13.0	0.1	13.1	17.8	0.1	17.9	23.0	0.0	23.0	28.1	1.2	29.3	36.0	0.8	36.8
Steam Electric	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3	0.0	2.3	4.5	0.0	4.5	6.8	0.0	6.8
Mining	1.2	0.3	1.5	0.8	0.4	1.2	0.4	0.5	0.9	0.3	0.5	0.8	0.2	0.6	0.8	0.1	0.7	0.8
Irrigation	1,174.7	2.4	1,177.1	1,034.3	2.3	1,036.6	2,060.5	2.3	2,062.8	2,003.8	2.3	2,006.1	2,692.7	2.4	2,695.1	2,695.2	2.4	2,697.6
Livestock	16.5	3.5	20.0	19.5	4.3	23.8	23.2	4.4	27.6	20.3	7.3	27.6	13.4	14.2	27.6	8.8	18.8	27.6
Zone Total Water	1,226.7	18.3	1,245.0	1,099.6	30.3	1,129.9	2,136.9	34.0	2,170.9	2,091.1	37.6	2,128.7	2,789.9	46.0	2,835.9	2,809.9	50.2	2,860.1
Zone 2																		
Population			192.3			198.5			233.9			268.0			310.7			359.5
Municipal	10.0	28.7	38.7	11.9	35.6	47.5	12.5	44.6	57.1	2.9	52.5	65.4	13.8	61.9	75.7	14.6	72.9	87.5
Manufacturing	0.8	2.0	2.8	1.4	3.0	4.4	1.9	4.4	6.3	2.5	6.0	8.5	3.2	7.9	11.1	4.0	10.3	14.3
Steam Electric	0.0	3.2	3.2	0.0	9.6	9.6	0.0	16.0	16.0	0.0	15.7	15.7	0.0	15.3	15.3	0.0	15.0	15.0
Mining	0.6	0.2	0.8	0.5	0.1	0.6	0.4	0.1	0.5	0.3	0.0	0.3	0.2	0.0	0.2	0.1	0.0	0.1
Irrigation	86.7	56.9	143.6	95.7	36.1	131.8	185.0	95.2	280.2	201.8	250.9	452.7	247.0	194.9	441.9	221.9	252.0	473.9
Livestock	1.3	7.8	9.1	2.2	8.6	10.8	2.2	10.3	12.5	2.2	10.3	12.5	2.2	10.3	12.5	1.8	10.7	12.5
Zone Total Water	99.4	98.8	198.2	111.7	93.0	204.7	202.0	170.6	372.6	219.7	335.4	555.1	266.4	290.3	556.7	242.4	360.9	603.3
Zone 3																		
Population			134.9			150.2			162.1			179.4			200.8			227.9
Municipal	13.2	9.5	22.7	4.0	29.8	33.8	4.0	33.2	37.2	4.1	37.1	41.2	4.3	41.7	46.0	4.3	48.0	52.3
Manufacturing	3.3	1.7	5.0	0.2	7.7	7.9	0.2	11.3	11.5	0.2	15.1	15.3	0.2	19.7	19.9	0.2	25.2	25.4
Steam Electric	0.1	5.9	6.0	0.1	5.9	6.0	0.1	10.4	10.5	0.1	17.0	17.1	0.1	23.5	23.6	0.1	30.1	30.2
Mining	0.4	0.0	0.4	0.3	0.0	0.3	0.1	0.0	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.0	0.0	0.0
Irrigation	2.9	35.4	38.3	2.1	36.5	38.6	2.1	39.8	41.9	2.1	43.2	45.3	2.1	43.2	45.3	2.1	43.2	45.3
Livestock	1.0	3.3	4.3	1.7	3.4	5.1	2.4	3.5	5.9	2.4	3.5	5.9	2.3	3.6	5.9	2.4	3.5	5.9
Zone Total Water	20.9	55.8	76.7	8.4	83.3	91.7	8.9	98.2	107.1	9.0	115.9	124.9	9.1	131.7	140.8	9.1	150.0	159.1
BASIN TOTALS																		
Population			506.0			555.0			624.2			702.1			800.9			919.7
Municipal	48.9	49.5	98.4	47.9	88.6	136.5	51.5	104.5	156.0	58.4	117.1	175.5	69.1	131.2	200.3	81.9	148.4	230.3
Manufacturing	12.7	4.5	17.2	14.6	10.8	25.4	19.9	15.8	35.7	25.7	21.1	46.8	31.5	28.8	60.3	40.2	36.3	76.5
Steam Electric	0.1	9.1	9.2	0.1	15.5	15.6	0.1	26.4	26.5	2.4	32.7	35.1	4.6	38.8	43.4	6.9	45.1	52.0
Mining	2.2	0.5	2.7	1.6	0.5	2.1	0.9	0.6	1.5	0.7	0.5	1.2	0.5	0.6	1.1	0.2	.7	.9
Irrigation	1,264.3	94.7	1,359.0	1,132.1	74.9	1,207.0	2,247.6	137.3	2,384.9	2,207.7	296.4	2,504.1	2,941.8	240.5	3,182.3	2,919.2	297.6	3,216.8
Livestock	18.8	14.6	33.4	23.4	16.3	39.7	27.8	18.2	46.0	24.9	21.1	46.0	17.9	28.1	46.0	13.0	33.0	46.0
Basin Total Water	1,347.0	172.9	1,519.9	1,219.7	206.6	1,426.3	2,347.8	302.8	2,650.6	2,319.8	488.9	2,808.7	3,065.4	468.0	3,533.4	3,061.4	561.1	3,622.5

a/ Population in thousands of persons, water requirements in thousands of acre-feet per year.

projected to range from 148.5 to 230.3 thousand acre-feet. Zone 1 is projected to account for 40 percent of total basin municipal requirements in 2000; in 2030, Zone 1 is projected to account for 39 percent of the total.

A range of 39.8 to 57.1 thousand acre-feet of municipal water requirements is projected in Zone 2 by 2000, most in Wichita County. Total municipal water requirements in Zone 3 are projected to range from 26 to 37 thousand acre-feet in the year 2000, of which Grayson County accounts for the greatest portion. By 2030, Zone 3 is projected to account for 22 to 23 percent of the total basin municipal water requirements.

Industrial

Manufacturing water requirements in 1980 were 17.2 thousand acre-feet in the Red River Basin. Projections of future water requirements for manufacturing purposes were made by decade and for a low and high case for each industrial group. In 1980, over 90 percent of total manufacturing water use was concentrated in five industrial groups: chemicals, petroleum refining, primary metals, paper products, and food products. Because of this concentration, careful attention was given to the future growth outlook for these industries in making the projections.

Manufacturing water requirements in the Red River Basin are projected to increase more than two times by the year 2030, to a potential high of 76.5 thousand acre-feet by 2030.

Steam-Electric Power Generation

Provided announced changes in installed capacity by the electric power companies operating in Texas materialize, most of the growth in steam-electric power generating capacity will occur in Zones 2 and 3 of the Red River Basin. Based on these projections, water consumption requirements in the basin will increase 22 to 26.4 thousand acre-feet annually by 2000 and 36.4 to 52 thousand acre-feet annually by 2030.

Agriculture

Irrigation

Irrigation water requirements were projected for two cases of change based on improvements in on-farm application efficiencies, reduction in ditch losses, changes in future resource costs and crop prices, and corresponding changes in cropping patterns to reflect more profitable crops. A low case projects demand for water based on the effects of changes in the above variables but with irrigated acreage held constant at 1980 levels in each zone for each future time period; a high case projects demand for water for irrigation constrained only by the requirement that irrigated farming produce a net positive return in excess of that possible from dryland farming and the requirement not to exceed the amount of irrigable soil in each zone. Thus, the projections of demand, low and high cases, based on the irrigation efficiency and market conditions mentioned above, give an estimate of the quantity of water needed for irrigation in each zone, at each decadal point for which projections were made. These projections of demand are compared to the projected supply of water locally available. When projected demand exceeds projected supply, the difference is a measure of shortage at that point in time.

Irrigation water requirements in the Red River Basin are projected to increase from the 1980 level of 1.4 million acre-feet by a projected maximum 75 percent by the year 2000 in the high case. In the year 2030, water requirements in the Basin are projected to range from 1.5 to 3.2 million acre-feet annually, low and high case, respectively, to irrigate from 1.2 to 2.5 million acres.

Zone 1 is projected to account for about 86 percent of total basin irrigation requirements in 2000; in 2030, Zone 1 is projected to account for about 84 percent of the total in the high case.

A range of 108.2 to 280.2 thousand acre-feet of irrigation requirements is projected in Zone 2 by 2000. By 2030, the range for this Zone is from 122.5 to 473.9 thousand acre-feet annually. Irrigation water requirements in Zone 3 are small by comparison with the other two zones, at a range of 31.1 to 41.9 thousand acre-feet annually for year 2000; in 2030, the range in irrigation requirements is from 31.1 to 45.3 thousand acre-feet per year in Zone 3.

Livestock

Livestock water requirements within the basin are projected to increase from 33.4 thousand acre-feet in 1980 to 46.0 thousand acre-feet by 2000. Livestock water use in 2000 is expected to be 27.6 thousand acre-feet in Zone 1, about 12.5 thousand acre-feet in Zone 2, and 5.9 thousand acre-feet in Zone 3. By 2030, it is estimated that 46.0 thousand acre-feet of water will be required annually to satisfy livestock needs in the basin.

Mining

Mining water requirements in the Red River Basin are projected to decline from 2.7 thousand acre-feet in 1980 to 0.9 thousand acre-feet in 2030. The estimated decline in the basin's mining water requirements will result from technological advances and greater water-use efficiency in the recovery of crude petroleum and natural gas. Increasing water requirements by nonmetal mining firms should correspond to expected increases in demand for construction-related raw materials.

Navigation

As part of the authorized Red River Waterway project, the Corps of Engineers has released a feasibility report of the economics of navigation. If this project becomes economically favorable, no additional freshwater requirement is anticipated for the Red River Basin.

Hydroelectric Power

There are currently no plans to expand hydroelectric power generating capacity in the Red River Basin beyond the existing 70 megawatts of installed capacity at Denison Dam.

WATER SUPPLY PROJECTS AND MEASURES TO MEET FUTURE BASIN NEEDS

Ground-Water Availability and Proposed Development

The ground-water availability through the year 2030 for the High Plains (Ogallala) Aquifer was estimated by imposing a set of total ground-water demands on a digital ground-water model of the aquifer developed by the Texas Department of Water Resources in 1982. The model analysis provided the following annual amounts of ground water available from the High Plains Aquifer within the Red River Basin from 1990 through 2030 by decade: 1.02 million acre-feet in 1990, 1.58 million acre-feet in 2000, 1.48 million acre-feet in 2010, 0.93 million acre-feet in 2020, and 0.69 million acre-feet in 2030. The model analysis also estimated that from 1980 through 2030 approximately 43 million acre-feet of ground water would be removed from storage, and that of the 29 million acre-feet remaining in storage in the year 2031 about 7 million acre-feet would remain in the "caprock" (tillable) area and 22 million acre-feet would remain in the "breaks" (nontillable) area of the basin. Within the Red River Basin, the High Plains (Ogallala) Aquifer receives on an average annual basis about 57.4 thousand acre-feet of recharge.

The approximate annual ground-water yield to the year 2030 within the remaining portion of the Red River Basin is 321.3 thousand acre-feet with the following amounts annually available by aquifer: 159.8 thousand acre-feet from the Seymour Alluvial Aquifer, 142.6 thousand acre-feet from the Blaine Aquifer, 14.0 thousand acre-feet from the Woodbine Aquifer, 4.4 thousand acre-feet from the Trinity Group Aquifer, 0.3 thousand acre-feet from the Blossom Aquifer, and 0.2 thousand acre-feet from the Nacatoch Aquifer. The quality of the ground water from the Blaine Aquifer is such that it can only be used for irrigation purposes. In the year 2030, the yields of the Seymour Alluvial Aquifer and the Trinity Group Aquifer within the basin would be reduced to their average annual recharge rates of 119.8 and 3.7 thousand acre-feet per year, respectively. These reductions decrease the total ground-water availability within the basin in 2030 to 280.6 thousand acre-feet (High Plains Aquifer not included).

The projected annual ground-water use within the Red River Basin by decade from 1990 through 2030 is expected to be from 0.91 to 1.73 million acre-feet per year (Table III-2-4). The approximate average annual projected ground-water use within the basin is expected to be about 1.31 million acre-feet per year. Of the 1.31 million acre-feet of average annual projected use about 86 percent is expected to be from the High Plains (Ogallala) Aquifer, about 9 percent from the Seymour Alluvial Aquifers, and about 2 percent from the Blaine Aquifer.

Surface-Water Availability and Proposed Development

Projected surface-water needs in the Red River Basin are estimated to exceed total basin existing and proposed surface-water resources beginning about 2000 and continuing through 2030 (Table III-2-4, Figure III-2-2). However, water shortages are projected to occur in irrigated agriculture by 1990. Projected surface-water needs for municipal and manufacturing purposes in the Red River Basin may be met from existing reservoirs in the basin and imports from adjacent basins until the year 2030 except in Zone 2.

Zone 1

By the year 2000, approximately 566 thousand acre-feet per year of irrigation water need is estimated to be unsatisfied in Zone 1 of the basin (Table III-2-5, Figure

Table III-2-4. Water Resources of the Red River Basin, With Projected Water Supplies and Demands, 1990-2030[1]

	Water Supply					Water Demand				Surplus or Shortage		
Decade	In Basin	Intra-Basin	Return Flow	Import	Total	In Basin	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	1133.4	—	—	—	1133.4	1219.6	—	—	1219.6	.0	(86.2)	(86.2)
Surface Water	507.1	—	32.9	22.2	562.2	151.7	—	114.4	266.1	306.5	(10.5)	296.0
Total	1640.5	—	32.9	22.2	1695.6	1371.3	—	114.4	1485.7	306.5	(96.7)	209.8
2000												
Ground Water	1731.2	—	—	—	1731.2	2347.7	—	—	2347.7	.0	(616.5)	(616.5)
Surface Water	498.1	—	41.4	25.4	564.9	245.6	—	125.1	370.7	269.2	(75.1)	194.1
Total	2229.3	—	41.4	25.4	2296.1	2593.3	—	125.1	2718.4	269.2	(691.6)	(422.4)
2010												
Ground Water	1657.4	—	—	—	1657.4	2319.8	—	—	2319.8	.0	(662.4)	(662.4)
Surface Water	495.3	—	48.7	26.2	570.2	428.7	—	132.6	561.3	243.0	(234.1)	8.9
Total	2152.7	—	48.7	26.2	2227.6	2748.5	—	132.6	2881.1	243.0	(896.5)	(653.5)
2020												
Ground Water	1125.7	—	—	—	1125.7	3065.4	—	—	3065.4	.0	(1939.7)	(1939.7)
Surface Water	492.4	—	57.5	26.6	576.5	403.4	—	137.6	541.0	213.5	(178.1)	35.4
Total	1618.1	—	57.5	26.6	1702.2	3468.8	—	137.6	3606.4	213.5	(2117.8)	(1904.3)
2030												
Ground Water	907.4	—	—	—	907.4	3061.4	—	—	3061.4	.0	(2154.0)	(2154.0)
Surface Water	551.6	—	67.7	27.3	646.6	491.0	—	145.8	636.8	244.9	(235.1)	9.8
Total	1459.0	—	67.7	27.3	1554.0	3552.4	—	145.8	3698.2	244.9	(2389.1)	(2144.2)

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions

Intra-Basin: A transfer of water among zones within a river basin.

Import: A transfer of water from another river basin.

Return Flows: Wastewater returned to a natural stream channel that can be recaptured at a downstream point.

Export: A transfer of water to another river basin.

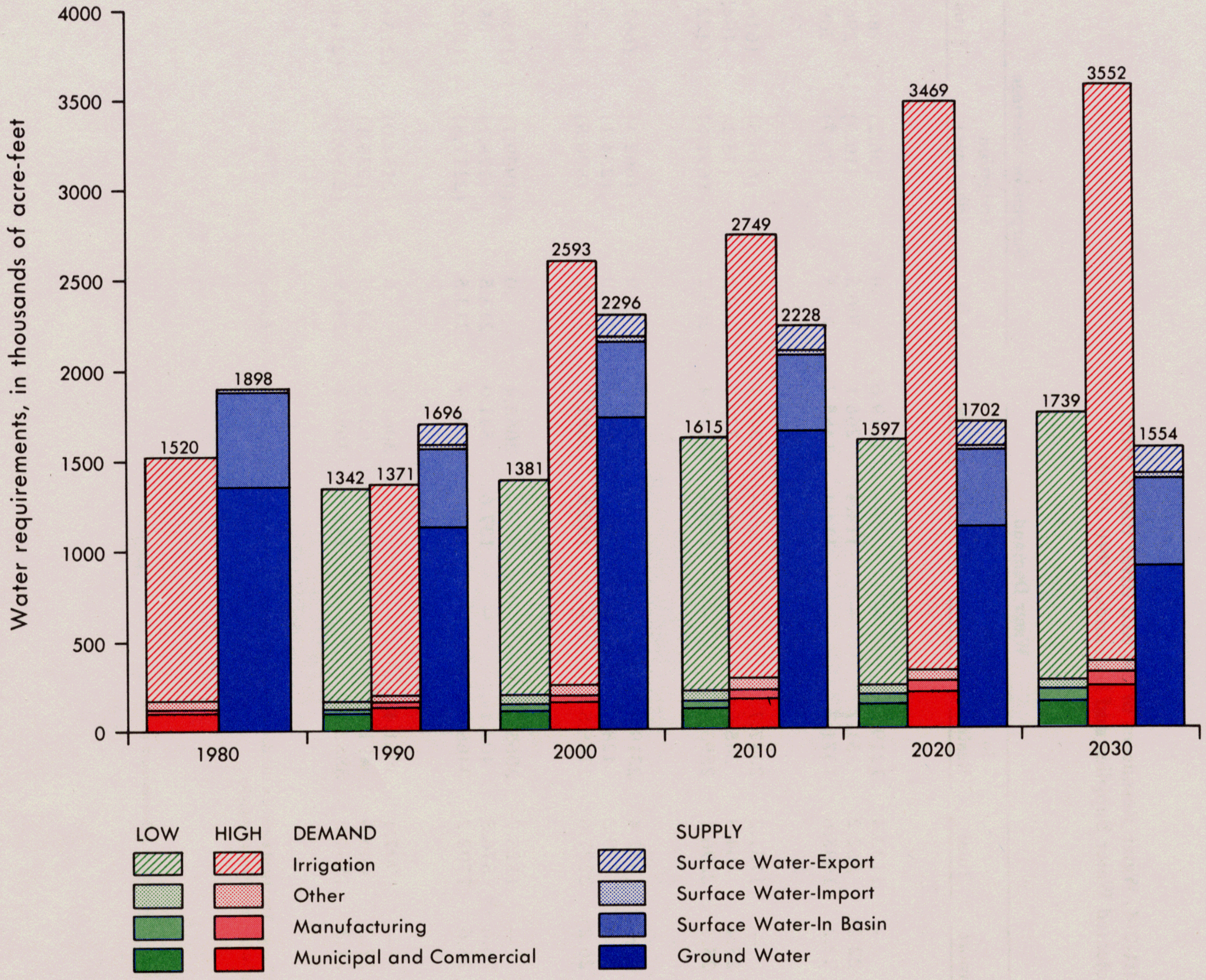

Figure III-2-2. Reported Use and Supply Source, With Projected Water Supplies and Demands, Red River Basin, 1980-2030

III-2-3). This shortage is projected to increase to about 2.0 million acre-feet per year in 2030. The shortages projected for this zone occur as a consequence of the decline of available ground-water resources in the area, primarily from the High Plains (Ogallala) Aquifer. Shortages for irrigation water use are estimated to begin by the year 1990, with an acceleration in the volume of shortage around the year 2010.

Sweetwater Creek Reservoir site is located on Sweetwater Creek in Wheeler County. Studies performed by the Red River Authority indicate that a reservoir at this site with a capacity of 65.8 thousand acre-feet would have a dependable annual yield of 5.2 thousand acre-feet of water for municipal, industrial, and recreational purposes. In 1982, the Red River Authority reactivated a water use permit application for Sweetwater Creek Reservoir previously submitted to the Department of Water Resources. Based upon local interest and diminishing ground-water resources in the area, the reservoir is proposed for operation by 1990. Continuing administrative and potential legal actions will most likely delay completion past 1990.

Should additional water needs develop in Zone 1 of the basin beyond the year 2000, potential reservoirs which could be constructed to meet such needs include Lower

Table III-2-5. Water Resources of the Red River Basin, Zone 1, With Projected Water Supplies and Demands, 1990-2030[1]

Decade	Water Supply					Water Demand				Surplus or Shortage		
	In Zone	Intra-Basin	Return Flow	Import	Total	In Zone	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	1013.3	—	—	—	1013.3	1099.5	—	—	1099.5	.0	(86.2)	(86.2)
Surface Water	22.7	.0	.0	19.8	42.5	23.3	3.7	.7	27.7	14.8	.0	14.8
Total	1036.0	.0	.0	19.8	1055.8	1122.8	3.7	.7	1127.2	14.8	(86.2)	(71.4)
2000												
Ground Water	1570.6	—	—	—	1570.6	2136.8	—	—	2136.8	.0	(566.2)	(566.2)
Surface Water	22.1	.0	.0	22.6	44.7	26.7	4.0	1.1	31.8	12.8	.0	12.8
Total	1592.7	.0	.0	22.6	1615.3	2163.6	4.0	1.1	2168.7	12.8	(566.2)	(553.4)
2010												
Ground Water	1470.6	—	—	—	1470.6	2091.1	—	—	2091.1	.0	(620.5)	(620.5)
Surface Water	21.7	.0	.0	23.1	44.8	27.3	4.4	1.3	33.0	11.8	.0	11.8
Total	1492.3	.0	.0	23.1	1515.4	2118.4	4.4	1.3	2124.1	11.8	(620.5)	(608.7)
2020												
Ground Water	948.2	—	—	—	948.2	2789.9	—	—	2789.9	.0	(1841.7)	(1841.7)
Surface Water	21.2	.0	.0	23.1	44.3	28.8	5.0	2.5	36.3	8.0	.0	8.0
Total	969.4	.0	.0	23.1	992.5	2818.7	5.0	2.5	2826.2	8.0	(1841.7)	(1833.7)
2030												
Ground Water	765.1	—	—	—	765.1	2809.9	—	—	2809.9	.0	(2044.8)	(2044.8)
Surface Water	20.8	.0	.0	23.2	44.0	28.3	5.8	3.3	37.4	6.6	.0	6.6
Total	785.9	.0	.0	23.2	809.1	2838.2	5.8	3.3	2847.3	6.6	(2044.8)	(2038.2)

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions
- Intra-Basin: A transfer of water among zones within a river basin.
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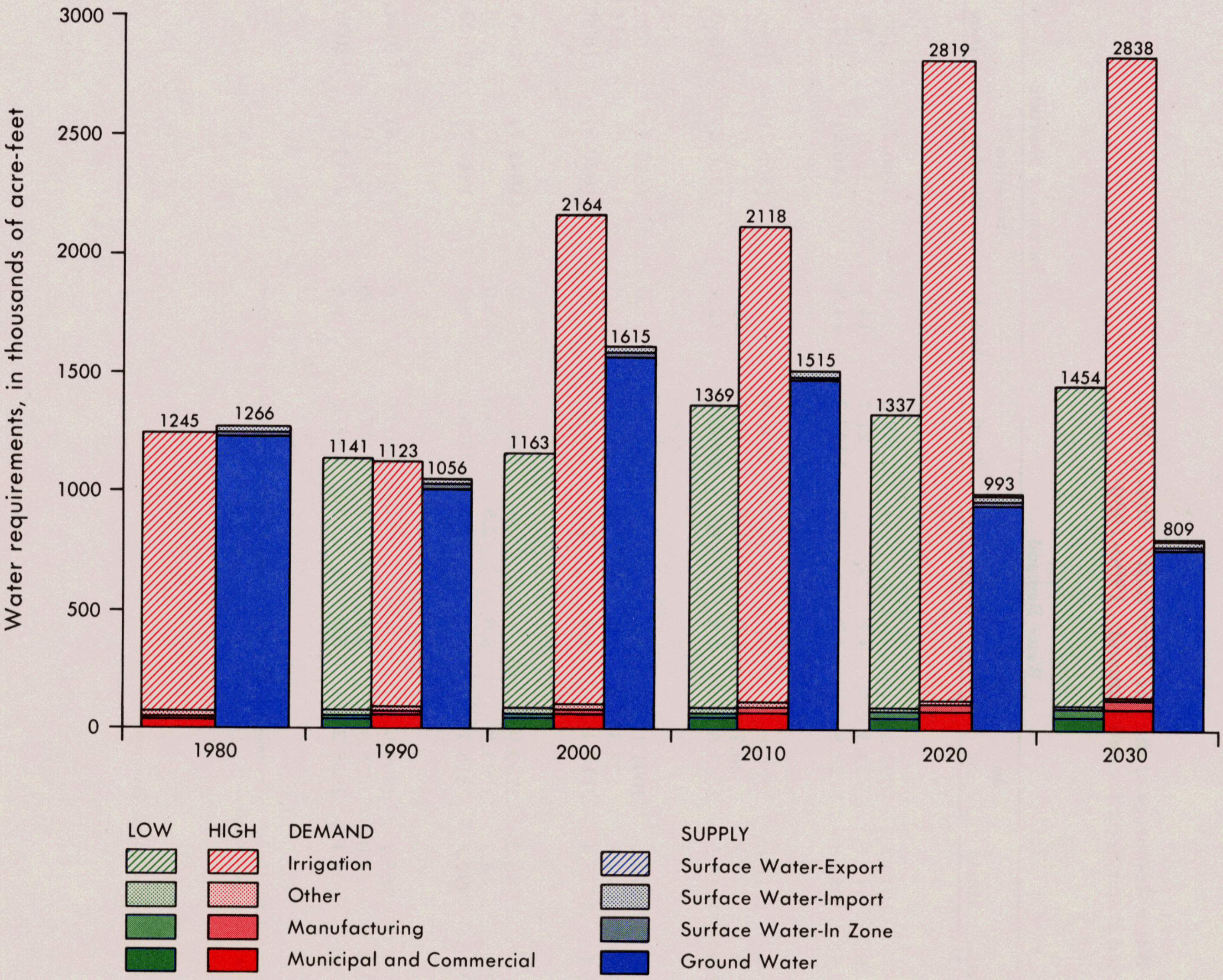

Figure III-2-3. Reported Use and Supply Source, With Projected Water Supplies and Demands, Red River Basin, Zone 1, 1980-2030

McClellan Creek Reservoir and Lelia Lake Creek Reservoir.

The Lower McClellan Creek Reservoir site is located in Gray County on McClellan Creek near its confluence with the North Fork of the Red River. This potential reservoir would also provide municipal and industrial water supply and serve recreation needs. The Lelia Lake Creek Reservoir site, located in Donley County, could supplement the Greenbelt Reservoir system should needs for additional water supply arise. The reservoir would have a capacity of about 17.2 thousand acre-feet and would also provide recreational benefits to the area.

Zone 2

Water requirements are projected to exceed water resources by 15.5 thousand acre-feet and 208.0 thousand acre-feet per year in Zone 2 by 2000 and 2030, respectively (Table III-2-6, Figure III-2-4). The year 2030 shortage includes a projected shortfall of 332.1 thousand acre-feet per year for irrigation and an annual surplus of 124.1 thousand acre-feet for municipal and industrial uses. This water surplus occurs as a consequence of existing and proposed surface-water development to be used exclusively for municipal and industrial purposes. Surface water is estimated to supply 250.2 thousand acre-feet

Table III-2-6. Water Resources of the Red River Basin, Zone 2, With Projected Water Supplies and Demands, 1990-2030[1]

	Water Supply					Water Demand				Surplus or Shortage		
Decade	In Zone	Intra-Basin	Return Flow	Import	Total	In Zone	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	111.7	—	—	—	111.7	111.7	—	—	111.7	.0	.0	.0
Surface Water	193.0	3.7	.7	.0	197.4	79.4	.0	1.5	80.9	121.4	(4.9)	116.5
Total	304.7	3.7	.7	.0	309.1	191.1	.0	1.5	192.6	121.4	(4.9)	116.5
2000												
Ground Water	151.7	—	—	—	151.7	202.0	—	—	202.7	.0	(50.3)	(50.3)
Surface Water	186.7	4.0	.8	.0	191.5	155.1	.0	1.6	156.7	101.0	(66.2)	34.8
Total	338.4	4.0	.8	.0	343.2	357.1	.0	1.6	358.7	101.0	(116.5)	(15.5)
2010												
Ground Water	177.8	—	—	—	177.8	229.7	—	—	229.7	.0	(41.9)	(41.9)
Surface Water	184.8	4.4	.9	.0	190.1	320.0	.0	1.7	321.7	90.3	(221.9)	(131.6)
Total	362.6	4.4	.9	.0	367.9	539.7	.0	1.7	541.4	90.3	(263.8)	(173.5)
2020												
Ground Water	168.4	—	—	—	168.4	266.4	—	—	266.4	.0	(98.0)	(98.0)
Surface Water	182.9	5.0	1.1	.0	189.0	277.5	.0	1.8	279.3	75.5	(165.9)	(90.4)
Total	351.3	5.0	1.1	.0	357.4	543.9	.0	1.8	545.7	75.5	(263.9)	(188.4)
2030												
Ground Water	133.2	—	—	—	133.2	242.4	—	—	242.4	.0	(109.2)	(109.2)
Surface Water	243.1	5.8	1.3	.0	250.2	347.2	.0	1.8	349.0	124.1	(222.9)	(98.8)
Total	376.3	5.8	1.3	.0	383.4	589.6	.0	1.8	591.4	124.1	(332.1)	(208.0)

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions
Intra-Basin: A transfer of water among zones within a river basin.
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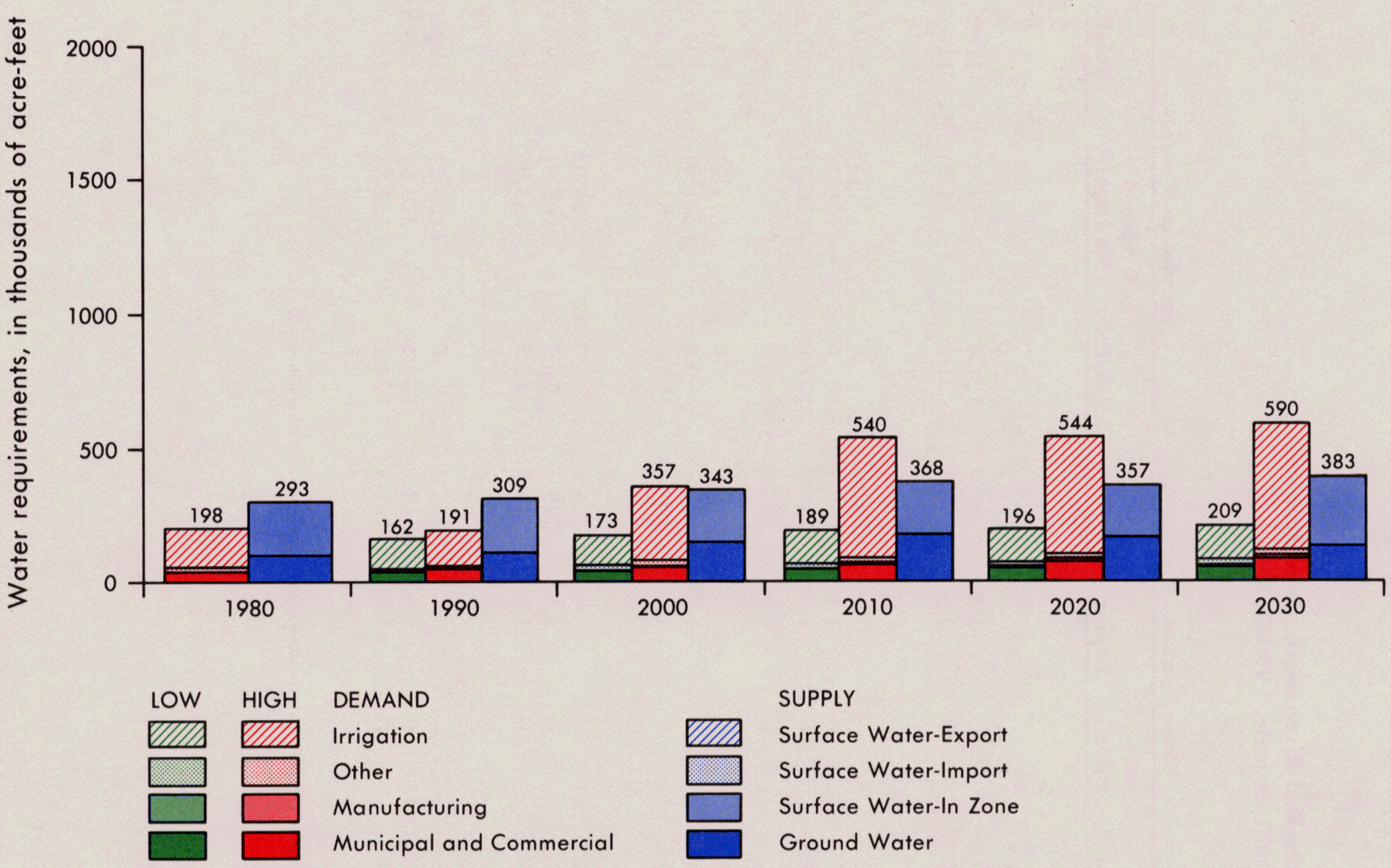

Figure III-2-4. Reported Use and Supply Source, With Projected Water Supplies and Demands, Red River Basin, Zone 2, 1980-2030

annually in 2030, with 1.8 thousand acre-feet exported for use outside of the basin. The irrigation water shortage occurs due to the limitation on available ground-water resources.

Shortly after the year 2020, additional supplies are projected to be needed in Zone 2 for municipal and manufacturing purposes for the City of Wichita Falls and adjacent Wichita County. The potential Ringgold Reservoir on the Little Wichita River is proposed as the source of the additional water needed in this area until well after the year 2030. Further studies will be needed by State and local interests to determine the economic feasibility of this project.

In Zones 2 and 3 of the basin, surface-water needs to the year 2000 and through 2030 can be met from existing major reservoirs and small local systems provided measures for alleviating natural salinity are implemented and are successful. Construction of all elements of the Arkansas-Red Basins Chloride Control Project will substantially improve the quality of surface-water supplies in Zone 2 and Zone 3. Construction of Canal Creek Brine Reservoir, Little Red River Brine Reservoir, Dry Salt Creek Brine Reservoir, and Truscott Brine Reservoir and the appurtenant low-flow dams, pipelines, and pumping facilities is essential. Natural salt-control facilities on the South Fork Wichita River is the only project which has received construction funding to date. Construction of all authorized salinity-control measures will improve the water quality in Lake Kemp, Lake Diversion, and Lake Texoma. The quality of the Red River below Denison Dam will also be significantly improved for beneficial uses by several states.

Studies are currently underway to determine feasibility of desalting water from the Lake Kemp and Lake Diversion system for use in the Wichita Falls area. Preliminary indications are that Lake Kemp-Lake Diversion water, to which the City of Wichita Falls has a permit for 31.0 thousand acre-feet, can be desalted by reverse osmosis and delivered to the city for substantially less than water from the potential Lake Ringgold. Other studies to determine the feasibility of desalting slightly to moderately saline ground-and surface-water in Zone 2 are also being conducted.

Zone 3

An excess in total surface-water supplies for all purposes other than irrigation is projected to occur in each decade through 2030 in Zone 3 of the basin (Table III-2-7, Figure III-2-5). However, shortages of 12.2 thousand acre-feet occur for irrigation needs as a consequence of limited ground-water resources. Surface-water supplies in year 2030 are estimated at 358.2 thousand acre-feet, with 140.7 thousand acre-feet of this supply exported to other basins. Approximately 114.2 thousand acre-feet of surface water is surplus for municipal and industrial purposes in year 2030.

Future availability of surface water in Zone 3 will be influenced by the Red River Compact which was ratified in December 1980. The Compact governs use of the waters of the Red River Basin (and the Sulphur River and Cypress Creek Basins in Texas) by the States of Texas, Oklahoma, Arkansas, and Louisiana. The Red River Compact provides that 400 thousand acre-feet of water in Lake Texoma be allocated to conservation storage. This conservation storage would be equally divided between Texas and Oklahoma. Therefore, for planning purposes it has been assumed that the water supply available to Texas from Lake Texoma in the future for municipal and industrial uses will be 200 thousand acre-feet annually.

Zone 3 of the Red River Basin may supply future surface-water needs in the adjacent Trinity River Basin. The North Texas Municipal Water District (NTMWD) is negotiating with the principals involved in Lake Texoma for up to 150.0 thousand acre-feet per year of water supply from that lake. Legislation has been introduced in Congress to authorize a reallocation of this same amount from hydroelectric power generation purposes to water supply use in Texas from Lake Texoma. Part of this annual reallocation could be used to meet the water needs of the Sherman and Denison areas in the Red River Basin. For planning purposes, it was assumed that 100.0 thousand acre-feet of annual water supply would be available to NTMWD. Additional studies will have to be performed by the Department and regional interests to examine the engineering alternatives and the economic, environmental, and institutional considerations that would be involved in such a major interbasin transfer of water.

The projected surplus water supplies in Zone 3 to the year 2030 are based on a comparison of water availability and currently projected water demands. Should additional water needs develop, several major reservoirs could be constructed in Zone 3; these projects could also serve other needs such as flood protection, recreation, fish and wildlife purposes, and irrigation. There are four potential, and one federally authorized, major reservoir projects which could be constructed in Zone 3.

Big Pine Lake is an authorized Corps of Engineers reservoir project located on Big Pine Creek in Red River and Lamar Counties. Big Pine Lake would provide flood protection along Big Pine Creek, water-supply storage for regional municipal and manufacturing purposes, recreation, and fishing and hunting.

Four potential reservoir projects in Zone 3 are Bonham, Pecan Bayou, Liberty Hill, and Barkman Creek. Bonham C. of E. (Corps of Engineers) Reservoir is one element of a combined plan for the Bois d' Arc Creek Basin, in Texas. The reservoir would lie in Fannin County on Bois d' Arc Creek and would provide flood control and a dependable water supply of about 27 thousand acre-feet per year. The reservoir is currently under study by NTMWD as an alternative water supply to the District's proposed Red River Diversion. The Pecan Bayou Reservoir site is located on Pecan Bayou near Clarksville in Red River County. The reservoir would provide a dependable annual firm yield of about 30 thousand acre-feet. Liberty Hill damsite is located on Mud Creek near New Boston in Bowie County. This reservoir would provide a dependable annual water supply of about 33.6 thousand acre-feet. Barkman Creek Reservoir is a potential industrial water-supply project located in Bowie County near Texarkana.

Water Quality Protection

A water quality management plan for the Red River Basin has been developed pursuant to the requirements of federal and State Clean Water legislation. An areawide water quality management plan has also been developed for the Texarkana metropolitan area. The purpose of these plans is to provide information for use in making water quality management decisions. The plans serve as a basic element in the State's overall water quality strategy and provide guidance in establishing priorities for construction grants for waste treatment facilities, permitting of wastewater facilities, revision of stream standards, and other program activities.

Construction costs associated with municipal wastewater treatment facilities needs have been estimated to be approximately $112.6 million for the planning period of 1980 to the year 2000. These costs are estimated for the entire Red River Basin with approximately $52.8 million required for Zone 3, $36.9 million for Zone 2, and $22.9 million for Zone 1. All costs are in January 1980 dollars

Table III-2-7. Water Resources of the Red River Basin, Zone 3, With Projected Water Supplies and Demands, 1990-2030[1]

	Water Supply					Water Demand				Surplus or Shortage		
Decade	In Zone	Intra-Basin	Return Flow	Import	Total	In Zone	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	8.4	—	—	—	8.4	8.4	—	—	8.4	.0	.0	.0
Surface Water	291.4	.0	32.2	2.4	326.0	49.1	.0	112.2	161.3	170.3	(5.6)	164.7
Total	299.8	.0	32.2	2.4	334.4	57.5	.0	112.2	169.7	170.3	(5.6)	164.7
2000												
Ground Water	8.9	—	—	—	8.9	8.9	—	—	8.9	.0	.0	.0
Surface Water	289.3	.0	40.6	2.8	332.7	63.8	.0	122.4	186.2	155.4	(8.9)	146.5
Total	298.2	.0	40.6	2.8	341.6	72.7	.0	122.4	195.1	155.4	(8.9)	146.5
2010												
Ground Water	9.0	—	—	—	9.0	9.0	—	—	9.0	.0	.0	.0
Surface Water	288.8	.0	47.8	3.1	339.7	81.4	.0	129.6	211.0	140.9	(12.2)	128.7
Total	297.8	.0	47.8	3.1	348.7	90.4	.0	129.6	220.0	140.9	(12.2)	128.7
2020												
Ground Water	9.1	—	—	—	9.1	9.1	—	—	9.1	.0	.0	.0
Surface Water	288.3	.0	56.4	3.5	348.2	97.1	.0	133.3	230.4	130.0	(12.2)	117.8
Total	297.4	.0	56.4	3.5	357.3	106.2	.0	133.3	239.5	130.0	(12.2)	117.8
2030												
Ground Water	9.1	—	—	—	9.1	9.1	—	—	9.1	.0	.0	.0
Surface Water	287.7	.0	66.4	4.1	358.2	115.5	.0	140.7	256.2	114.2	(12.2)	102.0
Total	296.8	.0	66.4	4.1	367.3	124.6	.0	140.7	265.3	114.2	(12.2)	102.0

[1] Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

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Return Flows: Wastewater returned to a natural stream channel that can be recaptured at a downstream point.
Export: A transfer of water to another river basin.

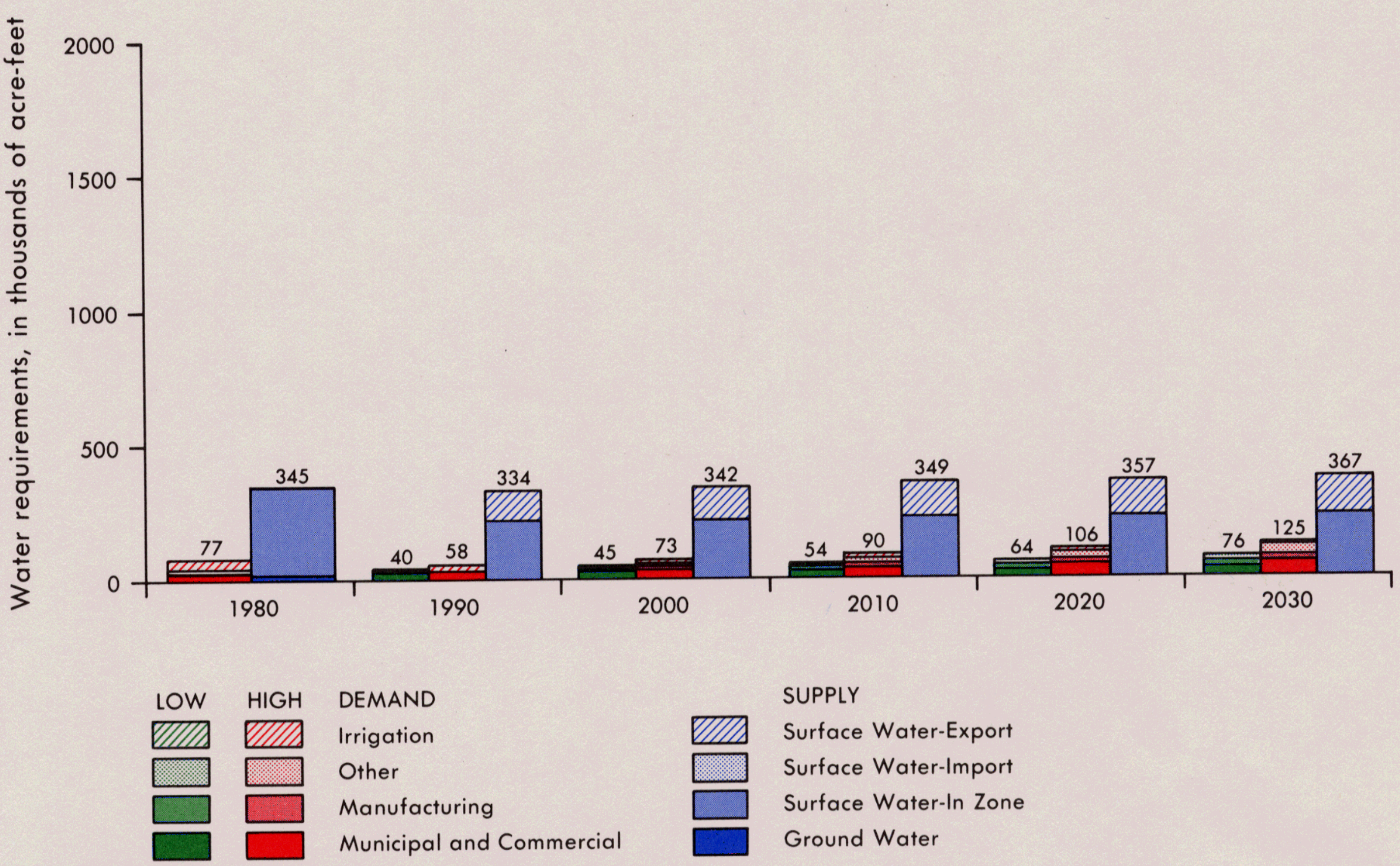

Figure III-2-5. Reported Use and Supply Source, With Projected Water Supplies and Demands, Red River Basin, Zone 3, 1980-2030

and are subject to revision as new data become available. The list of projects, with project costs for 1982-1989 at 1980 prices, is shown in Appendix B.

Additional water quality management costs, such as for control of agricultural, oil and gas, and industrial pollutants, cannot be estimated at this time, but are believed to be increasing.

Flood Control Measures

The three major reservoirs in the Red River Basin which provide flood control as a project purpose are Lakes Kemp, Texoma, and Pat Mayse. These three reservoirs have a combined flood-control storage capacity of 2.9 million acre-feet.

The Corps of Engineers is currently studying the basin above Denison Dam to evaluate water-resource problems and needs. The study report is scheduled for completion in December 1990. The Corps has planning and engineering studies on Lake Wichita, Holliday Creek at Wichita Falls, Texas. The proposed plan of improvement includes the replacement of the existing Lake Wichita Dam and 9.3 miles of channel improvement below the dam. Feasibility studies are also underway on McGrath Creek as part of the continuation of planning and engineering for Lake Wichita-Holiday Creek. These projects when completed will provide protection for the 100-year flood.

The Corps has completed preconstruction planning work on Big Pine Lake in Red River County and the project is awaiting funding to initiate construction. This project would provide 74,450 acre-feet of storage for flood control.

There is about 584 square miles of drainage area above 90 existing floodwater-retarding structures constructed under the U.S. Department of Agriculture—Soil Conservation Service Watershed Management Program within the Red River Basin. As of October 1980, an additional 41 structures with a combined drainage area of 279 square miles were planned for construction. Existing and planned structures are distributed evenly throughout all three zones of the basin.